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THESIS

APPLICATION OF AVATARS IN DISPLAY DESIGN TO SUPPORT SPATIAL AWARENESS UNDER VARYING WORKLOAD CONDITIONS

by

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Human performance in spatial orientation tasks is mainly determined by spatial awareness and the skills to transition from the current spatial attitude into the desired spatial orientation and position. Erroneous spatial awareness may lead to degraded task performance, to the loss of equipment, to serious injuries, or fatal aviation mishaps.

The use of UAVs is considered beneficial due to the reduction in risk to the human carrying out the "mission". However, the remote execution of such a mission is extremely demanding for the operator. If extensive use of UAVs is to become routine, a number of concerns that may influence their effective use needs to be addressed. When we consider the human-in-the-loop (HITL), then vehicle control and the use of autonomy are important issues for the end user.

Therefore this thesis will investigate the use of a virtual avatar in the flight simulator software (Weber Box) and conduct experimental proof of concept (conduct of experiments and analysis, evaluation and validation of the data of the concept using actual flight simulation software). Results of a study (conducted by Weber, 2006) indicated that the proposed design (Weber Box) seemed to strongly support spatial awareness in 3D orientation tasks. Time to assess a spatial situation decreases significantly, whereas accuracy of this spatial judgment at least maintains its level.

This study investigated human orientation performance in relation to display designs that support mental models of the user's spatial situation under varying workload conditions. The main goal is to support the pilot/operator with intuitive, 3D-based information which improves theirs spatial awareness and supports their mental model of spatial position, he/she is operating under, even with varying workload conditions. As a follow-up study has to be identified, determining whether varying workload affects performance between the two display designs, and if there is a significant difference to a set of properties which are essential for linking virtual avatars and spatial awareness.

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APPLICATION OF AVATARS IN DISPLAY DESIGN TO SUPPORT SPATIAL AWARENESS UNDER VARYING WORKLOAD CONDITIONS

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ABSTRACT

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Therefore this thesis will investigate the use of a virtual avatar in the flight simulator software (Weber Box) and conduct experimental proof of concept (conduct of experiments and analysis, evaluation and validation of the data of the concept using actual flight simulation software). Results of a study (conducted by Weber, 2006) indicated that the proposed design (Weber Box) seemed to strongly support spatial awareness in 3D orientation tasks. Time to assess a spatial situation decreases significantly, whereas accuracy of this spatial judgment at least maintains its level.

This study investigated human orientation performance in relation to display designs that support mental models of the user’s spatial situation under varying workload conditions. The main goal is to support the pilot/operator with intuitive, 3D-based information which improves theirs spatial awareness and supports their mental model of spatial position, he/she is operating under, even with varying workload conditions. As a follow-up study has to be identified, determining whether varying workload affects performance between the two display designs, and if there is a significant difference to a set of properties which are essential for linking virtual avatars and spatial awareness.

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I. INTRODUCTION

A. OVERVIEW

Most aircraft disasters are the result of inappropriate action or actions carried out by the pilots involved; a process known as "pilot error." Aircraft disasters are usually the outcome of a chain of events where many of the factors involved are insignificant in their own, but when combined with each other or with other factors they can result in a situation whereby the pilots involved become confused as to what is happening (a loss of situational awareness) and they begin to react in a way that the situations end up with catastrophic results (Paterson, 2000).

A significant causal factor as to why pilots become confused and begin to mishandle the situation in which they find themselves, is among many others poor cockpit design. Simple visual cues increase human awareness and perception and decrease reaction times. Humans are visual beings requiring visual cues to warn them of impending danger, especially in combat aviation. The simplest cues are those that allow individuals to immerse themselves in the situations to which they involve and must respond. Two-dimensional (2-D) display plan-views of aircraft attitude have real limits on what types of information and how much information they can present to the viewer without becoming disorienting or confusing. Situational Awareness requires a transition from 2-D to 3-D display perspectives.

The large number of aircraft accidents due to spatial disorientation lead to the opinion that these accidents may be attributed to improper instrument use and interpretation (Clay, 1993). The need to fly without visual references was an additional incentive to improve flight instruments. Technological breakthroughs enabled the development of multifunctional instruments and the so called glass cockpit (Mejdal and McCauley and Beringer, 2001).

The basic motivation for this thesis is the high impact of spatial disorientation (SD) on aviation mishaps. SD has become a major issue in modern fixed wing and rotor wing aviation mishaps prevention. Mishaps due to spatial disorientation claim nearly three times more lives than non-SD mishaps (Matthews, Previc, and Bunting, 2003).

Studies have shown that maintaining spatial awareness and preventing spatial disorientation is important for operating Unmanned Aerial Vehicles (Matsangas, 2004). Relationships between workload and operating UAV performance can be measured. Results of a study conducted by Weber, (2006) indicated that the proposed design (Weber Box) seemed to sustain remarkably well the spatial awareness in 3-D orientation tasks. Time to assess a spatial situation decreases significantly, with no loss in accuracy of this spatial judgment at least maintains its level. Judgment errors were minimized and the extreme errors were almost eliminated.

The purpose of the current study was to assess both subjective workload and associated operating UAV control performance under varying workload conditions for both experienced and novice operators/pilots. Specifically, the focus was to assess the relationship between subjective workload and various objective measures of simulated operation/performance both with and without the introduction of a secondary task involving operating more than one UAV simultaneously. Two experiments were conducted to investigate how the proposed design affects operators' orientation performance and to test the new effectiveness of the design concept under varying workload conditions.

B. THESIS ORGANIZATION

Chapter II reviews literature covering the major concepts, issues and systems underlying Situation Awareness, spatial awareness and spatial disorientation. The methods used are presented in Chapter IV. Chapter V covers the analytical strategy and presents the statistical results. Finally, conclusions and recommendations for future research are offered in Chapter VI and VII respectively.

II. LITERATURE REVIEW

A. SITUATION AWARENESS

Situation Awareness (SA) is a term used originally in the aircraft community and achieving it is perhaps the one of the most difficult aspects of an operator’s work. It has been defined by Endsley (1988) as: “...the perception of the elements within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” It is therefore clear that SA is necessary in order for people to perform tasks effectively (Endsley, 2000). Dominguez (1994) gives a similar definition, but places more emphasis on the impact of awareness on cue extraction and directed perception (i.e. its contribution to attention). For Dominguez (1994) then, SA constitutes a continuous extraction of environmental information, integration of this knowledge to form a coherent mental picture, and the use of that mental picture in directing further perception and anticipating future events.

Situation Awareness is most frequently defined in operational terms. Situation Awareness is knowing what is going on around you. We have been concerned mainly with people who need Situation Awareness for specific reasons, rather than individuals who has been largely outside the scope of human factors design efforts. For a given operator, therefore, SA is defined in terms of the goals and decision tasks for that job. The pilot does not need to know everything, but he/she does need to know at least the information to achieve a safe flight whether he/she is flying an aircraft or he/she operates a UAV as the related goal respectively. Although the "elements" of Situation Awareness vary widely between domains, the nature of SA and the mechanisms used for achieving SA can be described generically.

Shown in Figure 1 this definition helps to establish what "knowing what is going on" means.

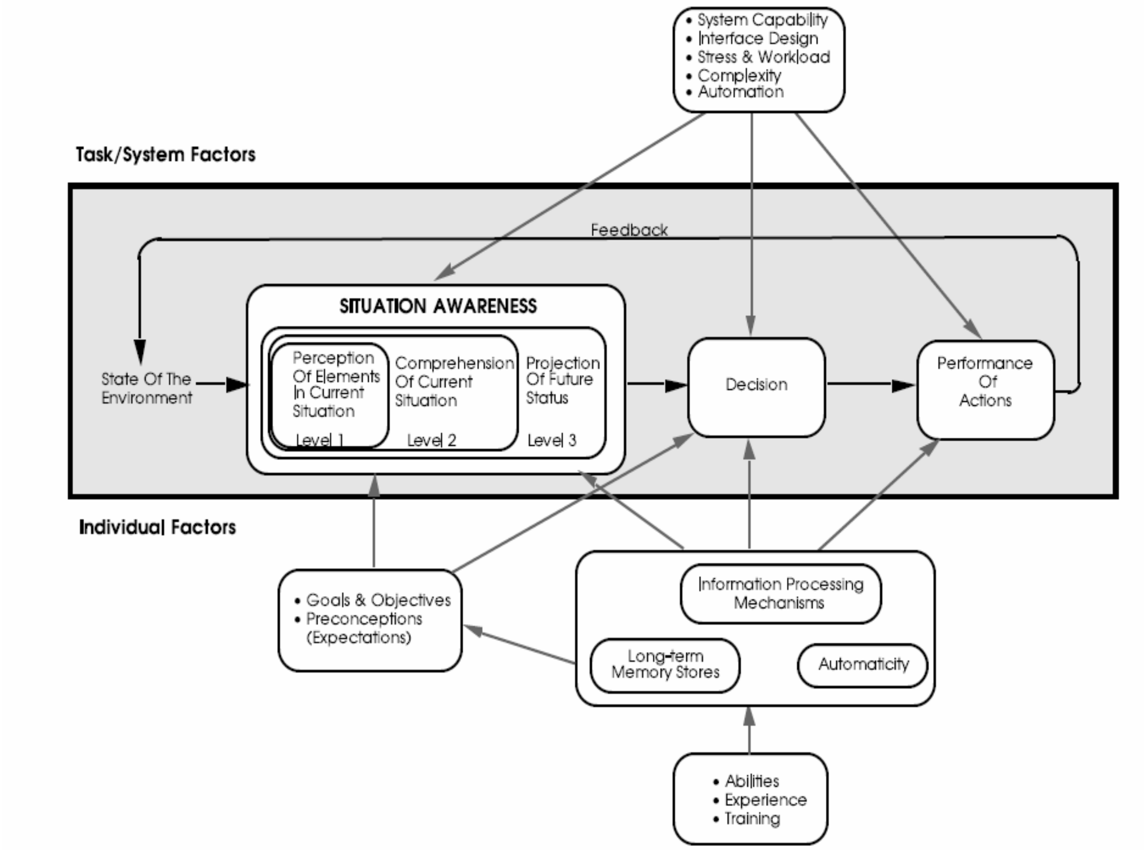

Figure 1. Model of SA in Dynamic Decision Making (From Endsley 1995b)

The enhancement of operator Situation Awareness has become a major design goal for those developing operator interfaces, automation concepts and training programs in a wide variety of fields.

Today's systems are designed and therefore capable of producing a huge amount of data, both on the status of their own components, and on the status of the external environment. Due to achievements in various types of data link and communications, systems can also provide data on almost anything anywhere in the world. The problem with today's systems is not a lack of information, but finding what is needed when it is needed fulfilling the principals “least to know” and “need to know”.

Unfortunately, there is a gap between the amount of data being produced and disseminated and the people's ability to find the information that is needed

and process it with the rest of the arriving information and the actual information that is required for their decisions. This information must be integrated and interpreted correctly as well. Issues of automation and "intelligent systems" have frequently only exacerbated the problem, rather than aided it (Endsley and Kiris, 1995; Sarter and Woods, 1995). In addition to designing systems that provide the operator with the needed information and capabilities, we must also insure that it is provided in a way that is useable cognitively as well as physically. We want to know how well the system design supports the operator's ability to get the needed information under dynamic operational constraints (i.e. How well does it bridge the information gap?). This design objective and measure of merit has been termed “Situation Awareness.” As an expansion, the previous general definition of SA (Endsley, 1988) has been found to be applicable across a wide variety of domains as discussed below:

1. Level 1 SA - Perception

In this first degree of SA, the perception of the elements in the environment, humans achieve SA by perceiving the status, characteristics, and dynamics of all relevant elements in the environment. For instance, pilots have to perceive important elements such as status of the own aircraft, other air traffic, terrain, flight parameters and warnings.

First, perception of cues (Level 1 SA) is fundamental. Without basic perception of important information, the odds of forming an incorrect picture of the situation increase dramatically. Jones and Endsley (1996) found that 76% of SA errors in pilots could be traced to problems in perception of needed information (due to either failures or shortcomings in the system or problems with cognitive processes). In military aviation, the number of tasks and the rate of change of the environment is very high because of the dynamic flight maneuvers, ground- and airborne-enemy activities, sophisticated weapon systems etc.

2. Level 2 SA - Comprehension

The second level of SA is comprehension of the current situation and is based on synthesis Level 1 elements. The key for Level 2 SA is that the human

must integrate Level 1 information to form a complete mental representation of the environment. Situation Awareness as a construct goes beyond mere perception however. It also encompasses how people combine, interpret, store, and retain information. Thus, it includes more than perceiving or attending to information, but also the integration of multiple pieces of information and a determination of their relevance to the person's goals (Level 2 SA).

This is analogous to having a high level of reading comprehension as compared to just reading words. Twenty percent of SA errors were found to involve problems with Level 2 SA (Jones and Endsley, 1996). Flach (1995) points out that "the construct of Situation Awareness demands that the problem of meaning be tackled head-on. Meaning must be considered both in the sense of subjective interpretation (awareness) and in the sense of objective significance or importance (situation)." A person with Level 2 SA has been able to derive operationally relevant meaning and significance from the Level 1 data perceived.

3. Level 3 SA - Projection

The third level of SA, the projection of future status, is the highest level of SA. It enables a person to predict, at least in the very near future, the evolving situation. This is achieved through excellent knowledge of the functioning and dynamics of the system and a comprehension of the situation (both Level 1 and Level 2 SA). Pilots have to constantly project their current situation into the future and will base their decisions on this prediction.

At the highest level of SA, the ability to forecast future situation events and dynamics (Level 3 SA) marks operators who have the highest level of understanding of the situation. This ability to project from current events and dynamics to anticipate future events (and their implications) allows for timely decision making.

4. SA as a Multidimensional Construct

The fact that SA is not a single ability creates serious problems for human factors researchers because it means they have no single measure of the phenomenon in which they are most interested. Indeed when Dennehy and

Deighton (1997) reviewed the literature from the period of 1979 to 1992, they identified no less than 28 different variables which had been used as measures of SA. Considering that these variables, Dennehy and Deighton set out to find the main SA subscales or "meta-categories," as follows:

- SA Meta-Category 1 - Pilot Knowledge: The first principal component was a composite measure of knowledge, per se.
- SA Meta-Category 2 - Anticipation and Understanding of Future Events: The second principal component was a composite measure of an ability cluster for anticipating and understanding future events.
- SA Meta-Category 3 - Capacity to Manage Stress, Effort, and Commitment: The third principal component was a composite measure of an ability cluster for managing stress and maintaining effort and commitment.
- SA Meta-Category 4 - Capacity to Perceive, Attend, Assess, and Assimilate Information: The fourth principal component was a composite measure of an ability cluster for obtaining and processing information from the world itself, both directly and from the cockpit dials and gauges available.
- SA Meta-Category 5 - Overall Awareness: The fifth principal component was a composite measure of general awareness, similar to the "g-factor" popular among some intelligence theorists.

In a further attempt to understand this clustering, Dennehy and Deighton adopted the Endler-Mischel "Interactionist Theory" (Endler, 1973; Mischel, 1973). This theory holds that it is impossible "to understand the role of an operator in isolation from the context within which she/he operates" (Dennehy and Deighton). The result is a "P-E Fit" model, one which tries to "fit" the person into his/her environment. Dennehy and Deighton characterized SA as the "operational space" provided by the two interacting domains in Figure 2.

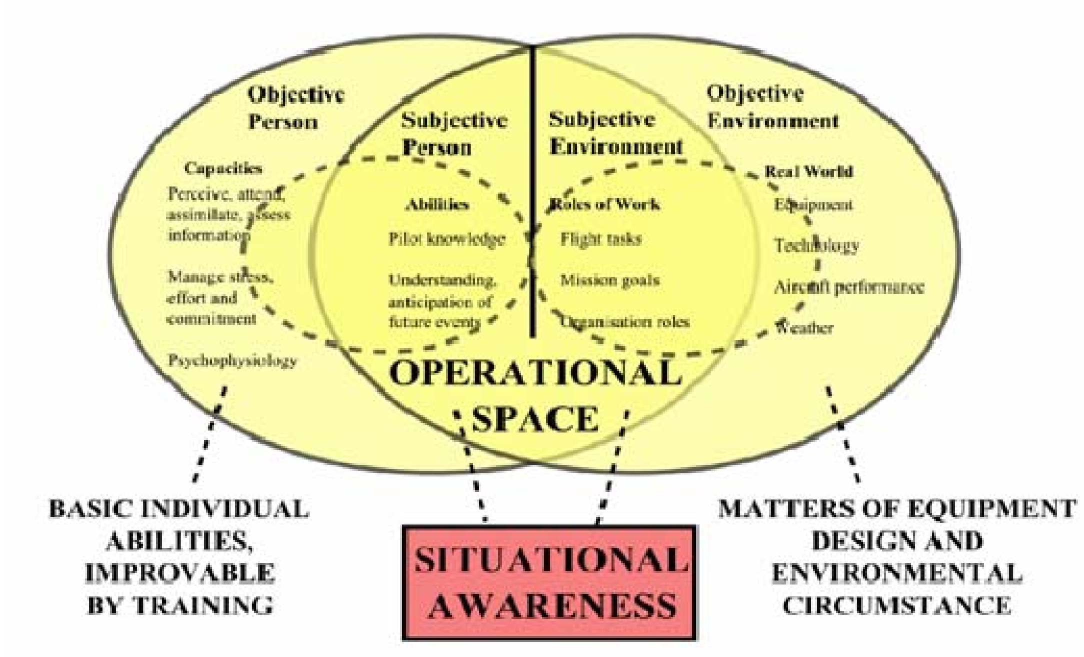

Figure 2. The Interactionist ("P-E Fit") Model of Situational Awareness (From Dennehy and Deighton 1997)

However, Endsley (1995, 1999) points out that it is simultaneously possible to divide up a pilot's declarative knowledge base (Dennehy and Deighton's first meta-category) according to the type of knowledge involved, as follows:

- Geographical SA: This knowledge domain stores facts about the physical world, for example, the heights of mountains, the nature of the terrain, the locations of alternative airfields, the direction of the prevailing wind, etc.
- Spatial/Temporal SA: This knowledge domain stores facts about the four-dimensional physical world (the three spatial dimensions, plus time), for example, aircraft position and speed, time into mission, etc. This is the most important for the current study.
- System SA: This knowledge domain stores facts about system states, for example, engine, control, or instrument malfunctions, fuel status, etc.
- Environmental SA: This knowledge domain stores facts about weather and visibility, together with such things as restricted (keep out) or prescribed (keep in) airspace.

- Tactical SA: This knowledge domain stores facts about the identity and capabilities of all other units in the vicinity (and, if military, that will include their combat intention as well).

Endsley brought all these concepts together into what he presents as an all-embracing theoretical model of SA (Figure 3).

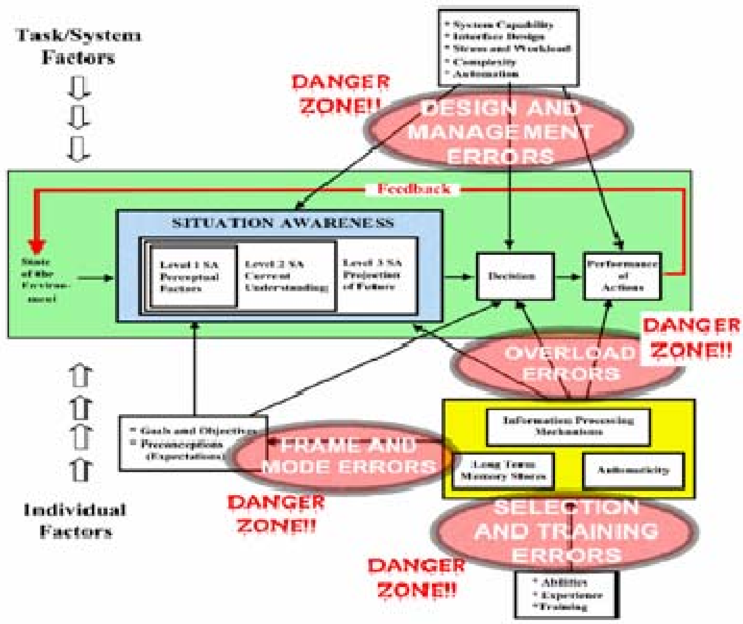

Figure 3. Model of Situational Awareness (From Endsley 1995, 1999)

Another approach is the so-called situated cognition model by Miller and Shattuck (2004), which describes SA model as a process, rather than certain fixed states as in Ensley's model. It is based on the one hand, on Pew's model of ideal SA, achievable SA and actual SA (Pew, 2000), which describes the problem of measuring SA. On the other hand, it includes the lens-model of Tucker and Hammond, of information selection, and filtering (Tucker, 1964). Miller and Shattuck's model focuses on processes rather than states and includes both human and machine elements of a system. It is oriented toward assessing human-system performance, tracks the evolution of activities and cognition, and links it to cognitive decision processes. From this perspective it describes the process of building SA starting at the ground truth, which is

selectively perceived by different layers of sensors (lenses). Every lens filters and transforms the received information. Then, the filtered information is processed by methods similar to Endsley's 3-Levels-of-SA model. In Miller and Shattuck's model, these levels are not independent levels of SA (Figure 4). They are, rather, specific cognitive processes which map additional aspects of the task and the environment like goals, expectations, personality etc. to the originally perceived information (Miller and Shattuck, 2004).

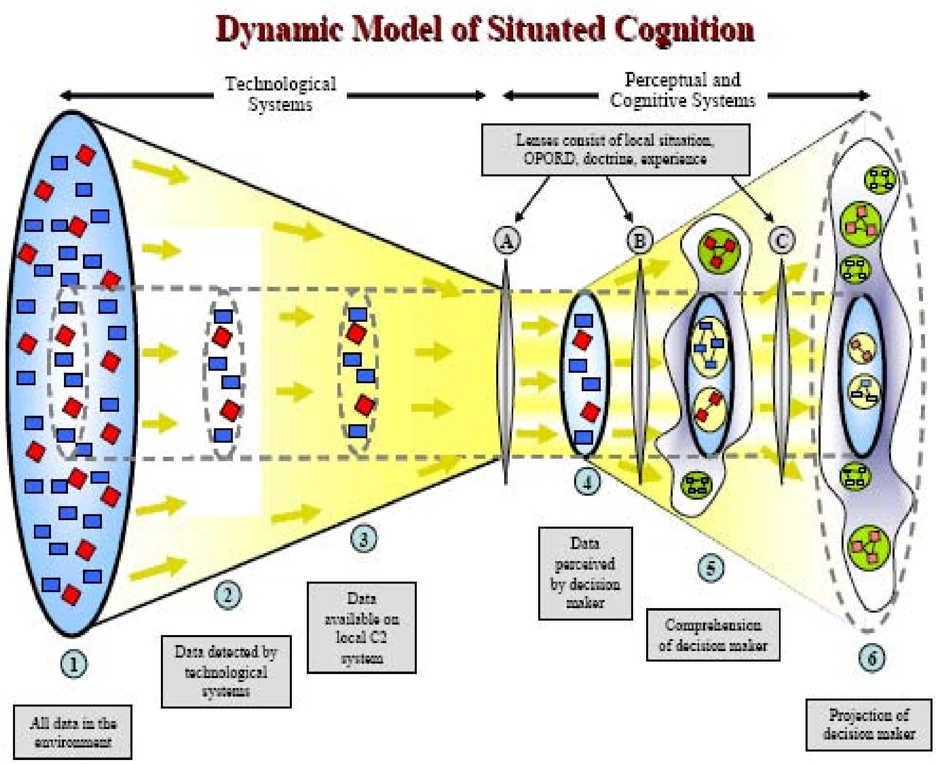

Figure 4. Dynamic Model of Situated Cognition (From Miller and Shattuck, 2004)

SA requires an operator to "quickly detect, integrate and interpret data gathered from the environment." In real-world conditions, Situational Awareness is hampered by two factors: data spread throughout the visual field and data that is noisy (Green, Odom and Yates, 1995). Understanding how data flow through the system, where the data may have been blocked, and how lenses may be

skewed is vital to knowing how to redesign systems and develop appropriate training (Miller and Shattuck, 2004). One of the greatest challenges facing the operators and technology providers is to match our increasing capability to gather, process, and display Situational Awareness information with a corresponding increase in our ability to use that information (Marsh, 2000). Increased availability of information about the situation may also be counterproductive with respect to time critical decision making. When decision makers expect information to be sparse, they tend to rely on judgment and experience to fill the voids. When information is massive and confusing, decision makers may often delay taking action until additional information can be gathered to fill voids or resolve ambiguities. They may reorient their decision making process from judgment based on experience to reliance on detailed analysis based on hard data. The result can be “analysis paralysis,” leading to a delay of the decision until it is too late (Marsh, 2000). Designers can help avoid these pitfalls by using properly designed technology coupled with well-trained operators, which will result in optimal human-system performance (Miller and Shattuck, 2004).

5. How Do We Get SA?

SA is the product of all various sources of information, as shown in Figure 5. Cues may be received through visual, aural, tactile, and olfactory or taste receptors. As we move towards the instantiation of remote operators in many domains (e.g., unmanned air vehicles, remote maintenance, etc.), a major challenge will be providing sufficient information through a remote interface to compensate for the cues once perceived directly (Endsley, 1995).

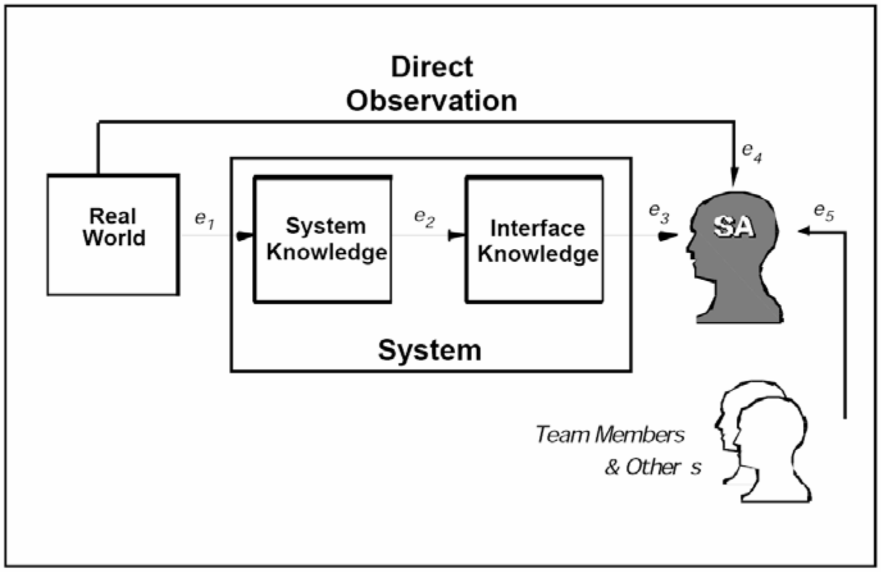

Figure 5. Sources of SA Information (From Endsley 1995c, 1997)

It is important to note that there is a tendency to focus on the information provided through the system and its operator interface which is not the only source of SA. In many domains, operators may be able to directly view and hear information from the environment itself, although in some cases they may not. It is important therefore that analyses of the SA provided by system designs also take into account that information that operators derive from other means. That is, what is the value added (or subtracted) by a given system taking into account what information one already gets via other means and what it may cost in terms of interference with that information (Endsley 2000). Of all the data the system possesses, some portion is displayed to the operator via its user interface. Of this information, the operator perceives and interprets some portion, resulting in SA. The role of others in the process of developing SA has also received attention. Verbal and non-verbal communication with others (including radio communication, hand signals and "wing-tipping" by other pilots) has historically been found to be an important source of SA information (Endsley 2000).

B. SPATIAL AWARENESS

1. Spatial Awareness

To gain a better understanding of the term spatial awareness, we define its meaning and other terms used in a similar context. Spatial Awareness is best understood as an important component of Situational Awareness. In a flight environment, developing Situation Awareness involves an assessment of numerous factors both internal and external. In order to identify the presence, magnitude, and possible intentions of a perceived threat, the operator must assess various aspects of aircraft behavior such as range, heading, altitude, speed, attitude (climbing or descending) and location on earth. In order to evaluate alternative responses to the potential threat the operator must take into account the status of defensive assets, considering factors that may limit available options, such as equipment malfunction or damage, fuel availability, atmospheric conditions, and terrain. All of these evaluations are made within a constantly changing environment and under highly stressful situations in which timing is critical and errors may be catastrophic.

Spatial awareness refers to an operator’s comprehension of the 3D geometry of the environment in which he/she is operating. Three-dimensional information contained in the environment includes the absolute distance of objects (distance from an observer to an object), the relative distance of objects (distance between one object and another object or the distance between different parts of a single object), and the true 3D shape of objects (Wickens, Todd and Seidler, 1989b). In a flight environment, this information is available to an operator directly from his forward field of view and other senses and from visual displays (Endsley, 1988). In some instances, for example at night or when objects are out of viewing range, the operator may have to rely solely on visual displays for a spatial representation of the environment (Andre, Wickens, Moorman and Boschelli, 1991). Visual displays are therefore critical to operators’ spatial awareness.

Currently, most operators rely on plan-view displays to develop mental models of the space in which they are operating. A major limitation of this type of display is that it can only represent information from two dimensions of space; the vertical dimension is typically encoded in a textual format. To obtain information about the vertical dimension of a track in the environment, operators are required to “hook” the track and press a button to obtain textual readouts of altitude. To determine aircraft attitude, operators must monitor altitude readouts over time and observe changes. Operators are therefore forced to integrate textual with spatial information and mentally reconstruct the 3D nature of the visual scene. This process requires valuable cognitive resources and decision-making time (Haskell and Wickens, 1993). These limitations of plan-view displays may be overcome by 3D display technology. Three-dimensional displays can depict all three dimensions of space in a completely spatial format thereby eliminating the requirement to integrate textual with spatial information. All of this information is contained within a single display which reduces the need for mental integration of information from multiple sources (Woods, 1984). Three-dimensional displays also provide a more natural or ecological representation of the “real world” (Wickens et al., 1989b). Three-dimensional computer graphics systems include perspective displays, stereoscopic displays, rotating displays, head-motion tracking displays, holographic displays, and multi-plane displays.

Ellis, McGreevy and Hitchcock (1984, 1987) examined how pilots’ avoidance maneuvers varied as a function of display type: plan-view versus perspective. Results from 10 airline pilots showed that the perspective display produced improved avoidance maneuvering; pilots took less time to identify collision hazards and recommend a maneuver, fewer errors were made in selecting a maneuver. Pilots were twice as more likely to select a vertical maneuver with the perspective display probably due to the more natural presentation of vertical separation. Bemis, Leeds and Winer (1988) compared a plan-view with a perspective display for the task of detecting an airborne threat and selecting the closest friendly aircraft to intercept the threat. The results from

21 naval operational personnel showed that fewer errors in detecting threats were made in the perspective display condition. The subjects were also more accurate and quicker at intercepting aircraft using the perspective display. Survey results showed that 19 of the 21 subjects preferred the perspective display.

2. Models of Spatial Awareness

According to the common definition of SA, in a three-dimensional (3D) orientation task, a person who has good SA has fast access to an accurate mental representation of the altering environment and may be able to predict his spatial situation in the near future. For example, an aviator with excellent SA may not be consciously thinking about the fact that there is an aircraft nearby. He is able to operate the aircraft proactively and correctly according to this situation. The pilot will do so quickly and precisely based on the ability to rapidly access the information from memory (Wickens, 2002). Thus, instrument design that supports SA will facilitate the appropriate reaction in uncertain situations.

Spatial awareness can be seen as a subset of Situation Awareness or rather a specific application of it and it has many, often vague definitions. For this study, we consider spatial awareness as an extension of spatial orientation, where spatial orientation is understood as the ability to recognize an object's orientation or position in three-dimensional space. It describes spatial awareness as the knowledge of their position relative to the desired flight route and the ground and its spatial attitude. In addition it includes the knowledge about the current flight maneuver; its own spatial behavior.

Wickens (2002) pointed out that a pilot's spatial awareness is determined by six crucial variables: pitch, roll and yaw (slip) of the aircraft, altitude, deviation from a flight path, and position along a flight path. More factors directly and indirectly, need to be continuously monitored to build a complete spatial model. Two of the most obvious are airspeed and stall-indicator. In addition, knowledge is needed about other air traffic, ground and weather. All variables are cross-linked, which means that one or more variables influence other variables in the future. For instance the combination pitch and airspeed may lead to later stalling

of the aircraft. Skilled pilots represent this linkage in a mental model and implement time constrains, latencies, and additional information within this model.

3. Measuring Situational and Spatial Awareness

An individual's SA is a relatively difficult construct to measure (Hancock and Desmond, 2001). Another issue is to determine how much SA is sufficient for the task. Endsley states that SA and performance measures are only linked probabilistically, and that there are no set thresholds of SA to guarantee a given level of performance (Endsley, Sollenberger, and Stein, 2000). Endsley et al. therefore propose relative levels of SA. In terms of the design issue, this would mean an increase in SA (after the addition of new layout) relative to the level measured prior to this introduction. Measurement should also enable comparison to the "ideal" SA: that is, perfect knowledge on all relevant aspects of a situation, with no gaps or holes in it. As we discussed earlier, Pew states that actual SA tends to be a subset of the achievable SA, which is again a subset of the ideal SA of any situation (Pew, 2000).

An individual's level of SA will be partially determined by the quantity and quality of the information available and by the individual's ability to utilize the important information sources and fill in for missing, imprecise, or incomplete information. Possible reasons for lowered SA are environmental factors such as lack of anticipation of vital factors (due to lack of awareness of the importance of these factors, or attention being focused on other things) (Entin, 1998). Entin refers to two types of SA measures: high-level and detailed SA. High-level SA measures facts according to subjects' responses to general questions about the current situation. The detailed SA is measured with questions about elements of the situation based on a broad-ranging assessment of operator SA requirements) (Gawron, 2000). Detailed SA reduces when information changes rapidly. In aviation tasks, operators may not have time to integrate all the incoming information into a coherent picture. Basic types of SA measures derive from

Entin's study of detailed and high level SA. One is based on the responses of subjects' to questionnaires that included questions designed to capture specific elements of the situation.

However, there are several other means by which SA can be measured, according to Pew (2000), which fall into the following categories. Direct systems performance measures are only applicable in very limited situations. Disruptions in order to disorient the operator can be introduced (Pew and Mavor, 1998). The operator's recovery time and the success of recovery tactics taken can be measured. Performance measures are often not sufficient to diagnose human-system relationships in detail. In many cases we have to measure subjective facts as mental models or mental workload as well (Endsley et al., 2003).

Subjective measures include self-assessments, expert judgments, peer ratings, and supervisor or instructor ratings. A different way to measure the gradient of change in SA is to infer it from objective performance measurements. In our opinion objective performance measurement should be conducted wherever possible. Subjective methods should be conducted to explain data of objective measurements.

Process measures are considered as very effective in measuring SA. These may include eye-tracing, head tracking, information acquisition, flight parameter analysis and so on (Endsley et al., 2003).

C. SPATIAL ORIENTATION - DISORIENTATION

Spatial disorientation (SD) is the most common cause of human-related aircraft accidents. SD requires the knowledge of both the physiology and psychology of the human in flight and, to a lesser extent but still important, an understanding of the physics of an aircraft in motion. When reading about an accident involving SD, terms like visual illusions, vestibular misperceptions, task saturation, weather, motion, and aircraft experience are commonly found. In the past, researchers aimed much of the countermeasures research at improving

their understanding of these misperceptions. However, in order to better understand the overall situation, researchers must start with the SD definition and arrange each condition into distinct categories (Figure 6).

The most widely used and accepted general definition is "A state characterized by an erroneous sense of one's position and motion relative to the plane of the earth's surface" (Freeman, et al, 1989-91). Prior to this accepted definition, researchers could not be certain that a particular incident qualified as SD or as another phenomenon altogether—often masking the real magnitude of the issue. To better support the use of this definition by researchers, pilots, physicians, and physiologists, an operational definition recently emerged—"An erroneous sense of the magnitude or direction of any of the aircraft control and performance flight parameters." (Gillingham, 1992).

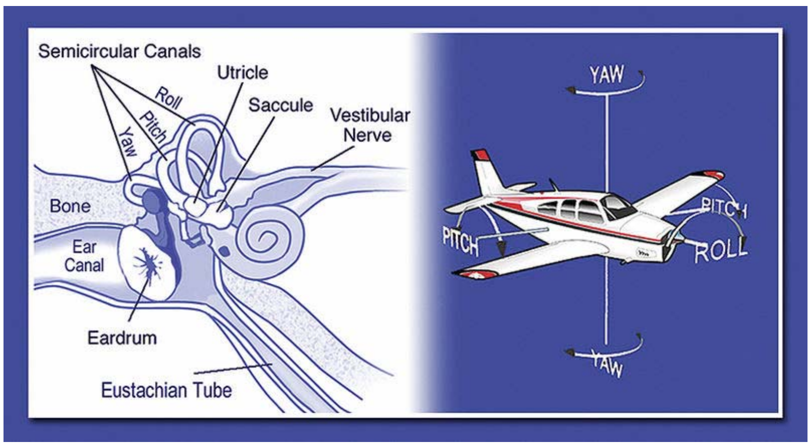

Figure 6. Inner ear with semicircular canals shown likening them to the roll, pitch and yaw axis of an aircraft (From www.atlasaviation.com)

Because of the different ways SD can occur, it is easier to study SD by separating it into three distinct categories: Type I—unrecognized, Type II—recognized, and Type III—incapacitating, where each type impacts the pilot in a different way (Heinle and Ercoline).

The first group, Type I—unrecognized SD, explains the phenomenon as a state where the pilot is unaware of the flight parameters described in the operational definition. This is the most common type of SD due to many psycho-

physiological variables (e.g., task saturation, canalized attention, fatigue, etc.). Many operators state that this as a simple failure of the pilot to maintain an appropriate instrument crosscheck. An example of Type I SD is the post-roll or Gillingham Illusion.

The second group of SD sensations encompasses those incidents that produce a recognized phenomenon known as a sensory mismatch or at least the awareness that something has gone wrong. This is labeled as Type II—recognized SD. An explanation of the classic Graveyard Spin Illusion demonstrates Type II SD (see Figure 7).

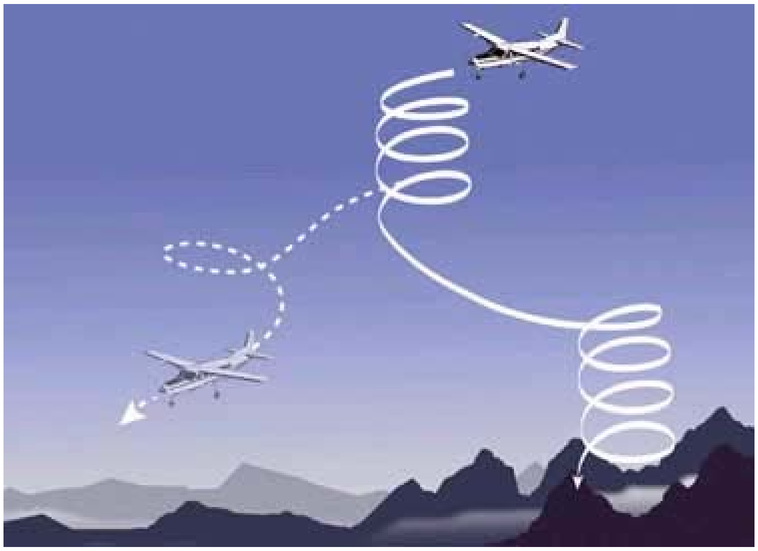

Figure 7. Graveyard Spin Illusion (From www.atlasaviation.com)

In this example, the pilot enters a spin, becomes stabilized in yaw, and realizes a need to move the controls opposite to the direction of rotation. Once the pilot applies the opposite controls, the aerodynamic result is a decrease in the aircraft's angular rotational yaw followed by a false sensation of the aircraft beginning to spin in the opposite direction. When this occurs and if the pilot looks at the aircraft turn needle or compass card, the pilot experiences a sensory conflict. The turn needle will indicate a turn in one direction, while the inner ear

sensation will generate a feeling that the aircraft is turning in the opposite direction. When this occurs, the pilot often suspects an instrument malfunction and does not recognize the situation as SD.

The third and last type of SD is the least common. Researchers call it Type III—incapacitating SD. Few studies of this type of SD exist, but researchers know that it does occur, through experience and pilot reports. An example of Type III SD is called the Giant Hand Illusion. The SD phenomenon has been intertwined with aviation since the beginning of manned flight, and only a concerted and coordinated research effort will make a difference in reducing SD mishaps. This effort begins with an understanding of the definition of SD, along with its three distinct types (Heinle and Ercoline).

D. HUMAN PERFORMANCE AND COGNITION

1. Human Perception and Cognition

The term cognition is used in several different loosely related ways. In psychology it is used to refer to the mental processes of an individual, with particular relation to a view that argues that the mind has internal mental states (such as beliefs, desires and intentions) and can be understood in terms of information processing, especially when a lot of abstraction is involved, or processes such as knowledge, expertise or learning, for example, are at work. The term cognition also is used in a wider sense to mean the act of knowing or knowledge. It was derived from psychological science which attempted to explain human behavior and reasoning (Matthews, Davies, Westerman, and Stammers, 2000). Unlike behaviorism, cognitive theory focuses on what is going on inside the person’s mind. Cognitive learning is not just a change in behavior; it is a change in the way a person thinks, understands, or feels.

Perception is defined as a direct consequence of selective attention, which involves the extraction of meaning from an information set processed by the human senses (Wickens et al., 2004). In this study we focus on higher level perceptions which answer questions of “What am I in?”, “Where I am?”, “What is

my attitude?”, “Where am I going?” and so on (Warren and Wertheim, 1990). Hence, we start with thinking at a level above human sensory systems and physical stimulus.

Endsley (1988; 1990; 1995) proposed a framework model based on information processing theory (Wickens, 1992). The cognitive mechanisms that are important for the development of SA are shown in Figure 8.

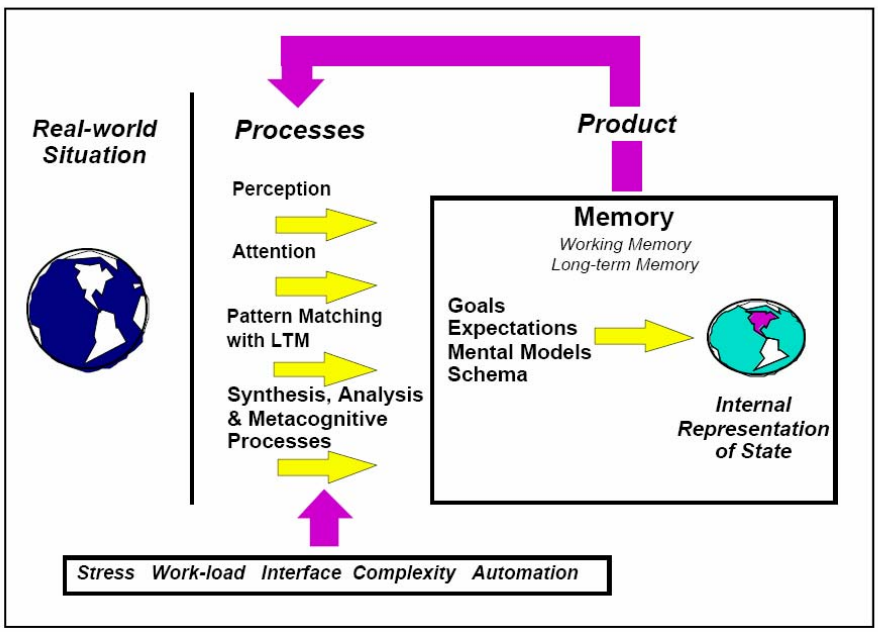

Figure 8. Mechanisms and Processes involved in SA (From Endsley 1988; 1990; 1995)

Wickens (1984) hypothesized that human attention capacity should be conceived as multiple resource pools, with dual-task interference being greatest when tasks compete for similar processing resources and least (or non-existent) when tasks draw from different resource pools.

2. Human Performance Models

Human performance models can be seen in three major tracks: Manual Control Models of human control in closed-loop systems, Task Network Models are concerned with fundamentally predicting the probability of success and performance time, and Cognitive Architectures Models are typically based on

theories of human performance capacities and limitations (Pew, 2000). The first two types of models arose from an engineering point of view and are based on control theory. Control theory describes any kind of system that has a feedback-loop.

Cognition and human performance are linked in cognitive architecture models. In order to accomplish this we have to address more factors and connections. Matthews et al. (2000) call these major factors the “energetics of cognition” and associated with it capacity, resources, and attention. Capacity is understood as the physiological and physical limits of human performance. Resources refer to a limitation of attention. We might not have enough attention to follow many parallel things that are happening simultaneously. Resource theory is widely as a base theory to study attention. Attention has selective and intensive characteristics. The selective aspect refers to a choice of reaction to a certain stimuli rather than to others (Matthews et al., 2000). Divided attention is the ability to react to two things or more at the same time or to accomplish two or more tasks or mental activities (Wickens et al., 2004).

We know that humans are not able to focus on a single object for more than some seconds. People have difficulty maintaining attention over a longer period. This is supported by various studies of the 1940’s and 50’s which did research on performance of radar and sonar operators and their detection time and error rate (Matthews et al., 2000). To explain sustained attention, four major models were developed over time: the filter theory, the expectancy theory, the arousal theory and the resource theory as described by Matthews et al. (2000).

The filter theory predicts that vigilance tasks in which signals are present only for a short period will contribute to a faster decrease of attention than tasks with signals that are present throughout a longer period.

According to the expectancy theory observers keep track of information to extrapolate the occurrence of future information. Over time, the observer’s internal estimate of the next information probability changes.

The basis of the arousal theory is that sustained attention leads to a lower level of arousal of the central nervous system (Matthews et al., 2000). It was shown by some experiments that cortical arousal level decays almost independently from the character of the task.

Matthews et al. (2000) state that resource theory describes experiments that show that task workload plays a major role in vigilance decline. This theory suggests that performance in demanding tasks is more sensitive to resource limitations by fatigue than simpler tasks. This position is supported by a number of single and dual-task experiments (Wickens and Gosney, 2003).

3. Working Memory and Attention

Several factors influence the accuracy and completeness of Situation Awareness that individual operators derive from their environment. First, humans are limited by working memory and attention. The way in which attention is employed in a complex environment with multiple competing cues is essential in determining which aspects of the situation will be processed to form Situation Awareness. Information must be integrated with other information, compared to goal states and projected into the future - all heavily demanding on working memory (Endsley 2000). Several recent studies have confirmed the role of attention in Situation Awareness. Endsley and Smith (1996) found that fighter pilots' attention to targets on a tactical situation display was directly related to the importance of those targets in their tactical tasks.

Attention to information is prioritized based on how important that information is perceived to be (Endsley 2000). Even experienced operators can make errors in this process, neglecting to attend to certain information over other information. Jones and Endsley (1996) found that the single most frequent causal factor associated with SA errors involved situations where all the needed information was present, but was not attended to by the operator (35% of total SA errors). This was most often associated with distraction due to other tasks. Correctly prioritizing information in a dynamic environment remains a challenging

aspect of SA. Good SA requires enough awareness of what is going on across a wide range of SA requirements (global SA) to be able to determine where to best focus one's attention for more detailed information (local SA).

4. Mental Workload

Consideration of the mental workload imposed by advanced technology is important to the military acquisition community and technology designers who must provide systems that do not overburden the user with operating tasks and information clutter. Resource or capacity models of mental workload postulate a limited quantity of resources available to perform a task, and in order to perform a task, one must use some or all of these resources. These models of workload address the difference between the amount of resources available within a person and the amount of resources demanded by the task situation (McCloy, Derrick and Wickens, 1983). Workload also refers to people's experience of cognitive task performance as effortful or fatiguing, which may index task demands and attentional overload (Mulder, 1986). Measures of workload can be classified into four categories: primary task measures, secondary task measures, subjective measures and physiological measures. In this thesis, data were collected in the first three of these areas.

5. Human Performance – Workload Measurement

We defined human performance as a measurable outcome of a certain task conducted by humans. Human performance is complex in its representation and outcome. In many tasks it is difficult to describe the outcome parameters that are expected. For instance, an attack pilot has to accomplish a wide variety of sub-tasks in order to fulfill his main task: attack a certain object. He has to operate the aircraft, navigate relative to the ground and in space, to coordinate his actions with wingmen, search, and select the target, react to enemy fire, maintain radio communication with several sources, select the appropriate weapon, chose the right moment to fire the weapon etc. Furthermore, each of these tasks consists of various subtasks (Wickens, 2002).

The amount of information processing and decision-making required in task performance impacts the workload experienced by the performer. Hart and Staveland (1988) add to this definition that "Workload is not an inherent property, but rather it emerges from the interaction between the requirements of a task, the circumstances under which it is performed, and the skills, behaviors, and perceptions of the operator."

Two major ways are used to measure human performance: objective measures and subjective measures. Objective measures are concerned with quantitative and qualitative outcomes of human performance. Therefore we measure physical variables like time and speed or we measure the quality of the outcome in terms of error rate or difference to the desired results. A subjective measurement assesses human performance through questionnaires or self-reports, which maybe considered as a weaker approach (Endsley et al., 2003). Objective performance based measurement, also called measures of effectiveness (MOEs) or measures of performance (MOPs) are considered as powerful tools for measuring the performance of a human-in-the-loop system and for identifying areas of inadequate Situation Awareness. The use of situations with testable responses can provide valuable insight into the user's Situation Awareness and how the user will act upon it (Endsley et al., 1998).

Subjective ratings, are the scales that are the most widely used workload assessment tools. The advantages of subjective workload assessments are ease of implementation, low cost, and limited intrusion on task performance. They are also useful in evaluating the potential for task overload among competing interface designs. They can be applied during the design process with mock-ups, prototypes, and simulators, as well as assessing workload on existing systems. Two subjective rating tools frequently used in aviation and other safety-critical environments are the NASA Task Load Index (NASA-TLX) and the Subjective Workload Assessment Techniques (SWAT) which have subscales assessing loads for time, mental effort, and psychological stress. NASA-TLX allows users to perform subjective workload assessments on operator(s) working with various

human-machine systems. NASA-TLX is a multi-dimensional rating procedure that derives an overall workload score based on a weighted average of ratings on six subscales. These subscales: Mental Demands, Physical Demands, Temporal Demands, Own Performance, Effort and Frustration. It can be used to assess workload in various human-machine environments such as aircraft cockpits; command, control, and communication (C3) workstations; supervisory and process control environments; simulations and laboratory tests (www.nrl.navy.mil).

Performance Data measures whether a portion or a user's entire task is selected for objective and quantitative measurement. Traditionally, performance-based measurements have included speed and accuracy data. Speed can be reaction time either to perceive an event or to initiate a response. Accuracy can be defined as whether or not a signal is perceived and if an appropriate response is made. Physiological Measures use numbers to assess a cognitive workload. These measures, in general, fall into one of two classifications: Background Measures - those measures not linked to any specific ongoing tasks or to the timing of any user activity or response and Task-Related - those measures specific to a user activity, response, or an event.

Questionnaires help to have a view into the cognitive model of the operator. By formulating the right questions the researcher is able to gain insight as to why the operator acted in one way or another. It helps to explain "hard" data of the objective measurement methods. One weakness is that questionnaires are subjective (Matthews et al., 2000), greatly depend on the way questions are asked and the experiment is organized to extract the desired information. In this study we use a set of performance-based measurement of spatial awareness and post-experiment questionnaires to evaluate subjective factors to better explain the objective measures (Prevot and Palmer, 2000).

III. PROPOSED DISPLAY DESIGN

A. GENERAL BACKGROUND AND DESIGN OF WEBER BOX

1. Background

Navigation awareness, in particular, refers, as stated in previous chapters, to the pilot's dynamic representation or mental model of the aircraft's orientation within two dimensions, space and time (Endsley, 1988). Flight control is characterized by three spatial coordinates *(x,* y, and z) and three axes of rotation (pitch, roll, and yaw), providing 6 degrees of freedom in Euclidian space. Conventional display formats, however, use multiple two-dimensional (2-D) displays to provide orthogonal views of three-dimensional (3-D) flight information. The mental model is formed by the pilot's perception of his or her orientation in the outside world (e.g., attitude, heading, altitude, airspeed), which is based on information obtained through the aircraft displays, the forward field of view, and/or directly from the pilot's senses (Endsley, 1988). Several human factors arguments could be made for the implementation of 3-D technology displays: whether a 3-D view of the airspace provides a more "natural" representation than conventional plan view (2-D) displays, or if a single 3-D perspective display provides a more "compatible" view by reducing the need to integrate mentally across several 2-D displays (Woods, 1984). According to the initial design for Weber Box, pilots would benefit with information displayed to them that would help establish and monitor SA, enabling them, to correctly judge the proper attitude at any given time. Thus, Weber's (2006) intention was to represent one display's information in the context of another (Aretz, 1991) in order to compensate for any wrong interpretation of the information provided. Besides the clear representation, a mapping of the real world is provided on an easy to learn set of instruments which creates less confusion and workload for the operator (pilot or UAV operator). Demanding less attention, the operator is able to reduce reaction time for tasks associated with distraction and interruptions.

2. Design Goals and Purpose

The major design goal is to support the operator’s spatial awareness in an easily understandable and intuitive way, even when subjected to an increased workload. Traditional flight instrument design is based on historic design features, which are very abstract and non-intuitive (Figure 9). Conventional flight instrument displays require the pilot to scan instruments looking at or near each of a number of instruments in succession to obtain information. Over the years many different layouts have been experimented with; however there is now one accepted layout, which all modern airplanes adopt. This is known as the basic T.

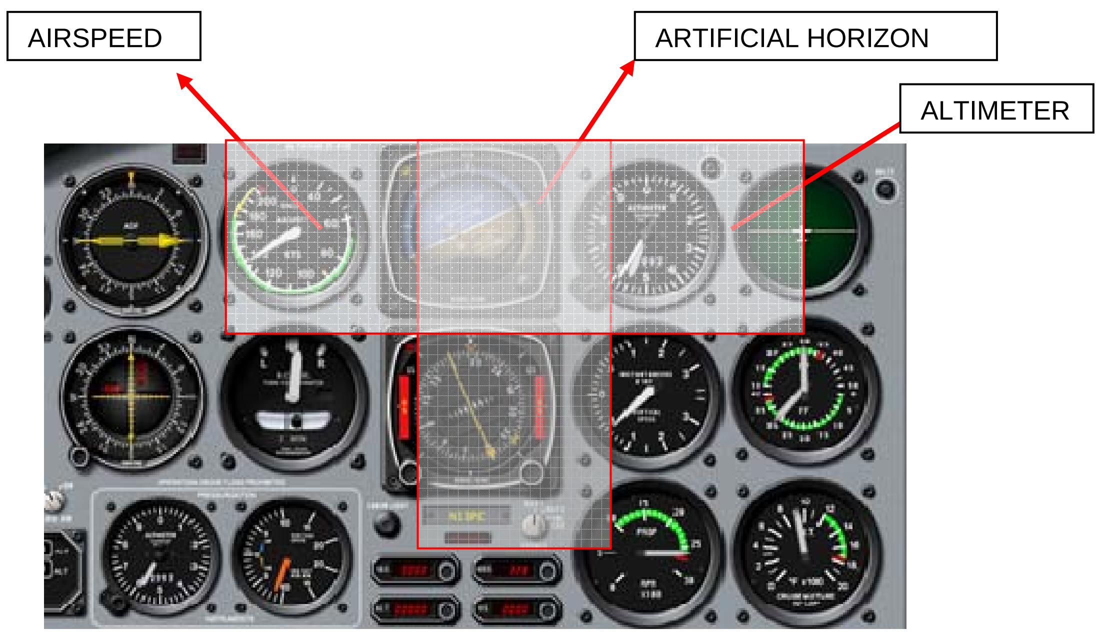

Figure 9. Traditional flight instrument design (Screenshot from *X-Plane* flight simulation)

The common instrument design shown in Figure 9 demands extensive training to develop the necessary skills to interpret and use these displays (Headquarters Department of the Army, 1984). In extreme situations, fatal accidents have occurred because of misinterpretation of the cockpit instruments (Roscoe, 2002).

Because current aircraft display design inherits many poor design features from its historical roots, Weber (2006) decided to introduce a new way to represent major elements of flight dynamics. The purpose of the proposed design was to introduce an innovative way to display spatial information on flight instruments. The design concept therefore breaks with traditional flight instrument design. The display was not designed to substitute any of the traditional instruments. It rather supports the operator of an aircraft in extreme or ambiguous situations by intuitively representing an appropriate level of spatial awareness (Weber, 2006).

3. Basic Design Concepts

The overall display layout facilitates the implementation into HUDs or HMDs. Principles of abstract and simplified symbology and restrictive uses of colors are applied (Weber, 2006).

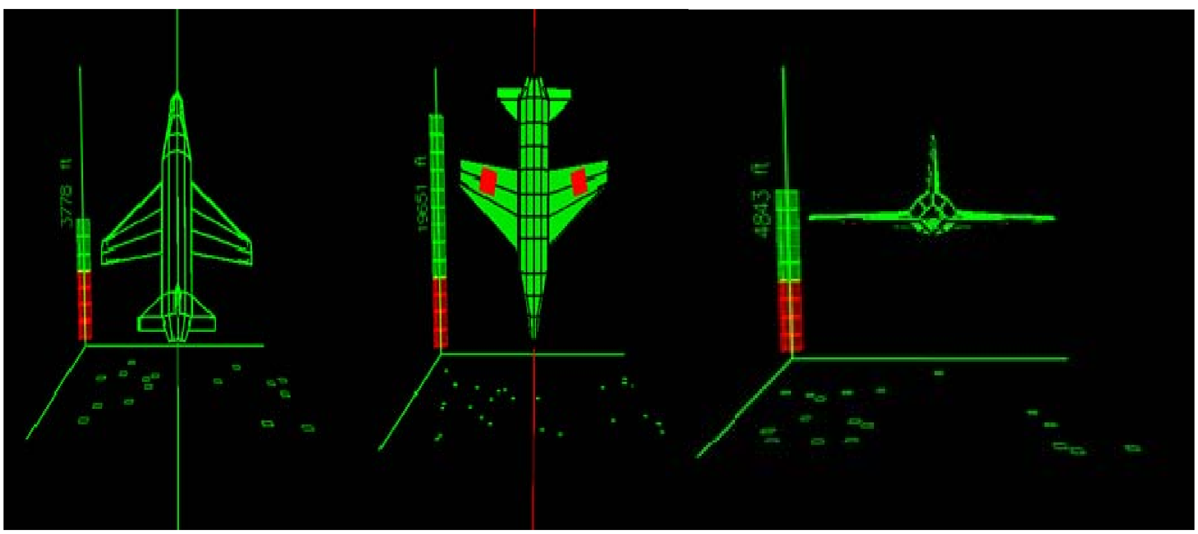

Figure 10. Screenshot: overall display design (From Weber, 2006)

The texture design of the aircraft was aimed to support definition of all possible spatial orientations. The top side has a green wire frame on black background; the under side has a black wire frame on green background (Figure 12). Furthermore, the top side texture has only longitudinal lines, whereas the bottom side has squares. The application receives data from any flight simulator

via network communication using the UDP standard. The default UDP port was 49001 while during the experiment it used the UDP port 49002. The UDP client demands the X-Plane™ data structure specifications.

IV. METHOD

A. METHODOLOGY

1. Experiment Goals and Purpose

The goals of this study was to further implement, and evaluate the Weber Box proposed display design (Weber, 2006) that supports or enhances spatial awareness in 3D orientation tasks while having increased workload conditions. In order to accomplish this goal we have to assess the impact of the proposed display design on people's spatial awareness in an environment that varies workload experimentally.

2. Research Questions

Due to the limited scope and assets of this study this evaluation sought to answer four main questions: (1) How will the display design, compared to a traditional display layout, influence the time to assess a static spatial orientation? (2) How will the same display design influence the time to assess a static spatial orientation while operating more than one UAV (3) What is the subjective impression of the design to the operator? (4) Will the impact and the subjective judgment be different for participants with a strong aviation background versus participants without an aviation background (pilots/non pilots)?

The answer to the first two questions provides insight into how people are able to build their mental picture/model of the current spatial situation even when they have to operate under a varying workload environment. The time it takes them to mentally construct their spatial awareness enables us to come to conclusions about the effectiveness of the proposed design to support the mental process of generating spatial awareness. It allows us at least estimate the impact of the display on real world tasks and enables the participants to evaluate the design in the context of a goal-based task.

The answer of the third question gives us insight about the impression of the participants beyond objective performance measurements. It enables us to bring the MOEs in context and may help to diagnose ambiguous outcomes.

The last question provides information about the relationship between personal background/training and the user acceptance of the proposed design. Perhaps a pilot with hundreds or thousands of hours of experience with traditional flight instruments will find it much easier to interpret and use the old instrumentation and harder to adapt to the new one operating under an increasing workload environment (multiples UAVs). The opposite might be the case for non-aviators.

3. Constraints and Assumptions

Since the experiment involves human participants we had to apply for approval by the Institutional Review Board (IRB) was required. The experiment was approved as proposed (Appendix A).

The flight dynamics were provided by a commercial flight simulation program, X-Plane® by Laminar Research™ in version 7.13. X-Plane does not allow storing complete flight situations, including flight dynamics. We used the original cockpit layout generated by X-Plane, and a model of a Piper PA-46 Malibu, which is a small single propeller turboprop aircraft.

4. Technical Equipment

The experiment took place at the MOVES Institute, Naval Postgraduate School in Monterey, California. The proposed display was implemented on a/two personal computer (Laptops) in addition with a/two 17-inch TFT monitor respectively, which was placed in front of the participant. All Laminar Research software uses OpenGL so a 3-D accelerator card that can run OpenGL was required to use the latest software. At minimum the configuration should be for Windows, Pentium 1ghz+, (or for Macintosh PowerMac 800+), with disk space 4 gig, a 3-D card, VRAM at least 32 meg, and a monitor at a 1024x768+ resolution. A peripheral input device that looks similar to a UAV control device, a computer joystick (USB) was used that allowed the participants to control two UAVs similar to controlling an airplane in a flight simulator. The time required for the subject to assess spatial attitude for both sub-experiments was stopped by hand using a digital hand stopwatch type SPORTLINE®.

5. Data Collection Methodology

Both sub-experiments stopped the time to assess the current spatial situation by hand with an estimated precision of ±0.1 seconds. The precision of the spatial judgments was measured by evaluating the drawings for pitch and roll out of the provided schema (Appendix F). The drawings were evaluated in 15° steps based on the error from the given values. Hence, the precision was ±15°. Thus, errors within 15° rounded to the next value.

The subjective self-assessment provided a scale of five judgments in every questionnaire. Demographic data were collected by a pre-experimental questionnaire (Appendix E). Participants completed the NASA-TLX questionnaire immediately following each of the two sets.

All participants were exposed to all instrument setups and all sub-experiments. The order of presentation of the two of displays was counterbalanced using a randomized subject assignment procedure. Selection was done as follows:

- List participants names
- Generate random numbers of enough digits that each exceeds the size of the sampling list by several digits. This makes duplication unlikely.
- Assign the random numbers arbitrarily to individuals in the sampling frame list.
- Sort the list of random numbers, carrying along the sampling frame list.
- Now the first **n** values in the sorted sampling frame column are a simple random sample (SRS) of n values from the entire sampling frame.

Odd-numbered participants started with the traditional instrument setup; even-numbered participants started with the new instrument setup. This ensured that learning effects were counter-balanced over the experiment.

6. Data Analysis Methodology

The data were recorded using spreadsheets. Every sub-experiment allows the participant six individually measured and recorded trials. The data were analyzed by commercial statistical software JMP® version 5.1.2, using various

methods e.g. linear regression analysis, residual analysis, ANOVA and paired t-tests. Two major questionnaires, subdivided into one pre-experimental demographic questionnaire, and two post-experimental subjective evaluation questionnaires where administered in this experiment (Appendix EandG). The questionnaires were given for several reasons: as to develop a secondary method to determine the effects of the dependant variables, and to enable a correlation between a participant's subjective and quantitative data and to assess the relationship between subjective ratings of the workload and objective measures of performance between experienced and inexperienced (novice) operators.

B. EXPERIMENT DESIGN

1. Basic Experiment Design

The experiment was designed to compare differences in time/speed and accuracy/precision while changing one variable (display design), while tested in different workload conditions (two UAVs). The dependent variables were the outcomes in terms of differences in time and accuracy. The independent variable was the instrument layout with two different designs, the traditional "basic T" and the new Weber Box. Participants and whether operating under varying workload conditions, meaning operating one or two UAVs simultaneously.

The main idea was to have a set of two sub-experiments with static task in order to measure the time and accuracy of the participant's assessment of their spatial situation. It also served the purpose of making the participants familiar with the use and interpretation of the instruments and displays.

The participants were told that they were the operator of a combined rotor-/fixed-wing based Unmanned Aerial Vehicle (UAV). The UAV is on a test flight and enters a sector of bad weather. The data-link connection to the UAV was interrupted because of the weather conditions (simulated by switching off the 17" monitor). At given time the experimenter freezes the simulation software, providing equally difficult attitudes that have to be determined.

2. Experimental Procedure

Every participant went through a series of experiment sets. First the participant was introduced to the experiment. Then the participant filled out the necessary paperwork, including consent form, privacy statement, and minimal risk information form (Appendix A). After the initial brief, the participant had the opportunity to become familiar with the flight simulator and control devices by a free self-paced flight training while assisted by the experimenter.

After taking the pre-experimental training the participant started with task one and the given instrumentation setup (with or without the new instrument – Figure 11). Subsequent to this first sub-experiment, the participant starts the second sub-task, while this time he/she had to operate under an increased workload, i.e. controlling two UAVs. Each sub-experiment set was scheduled for 20 minutes with an optional 10 minute break.

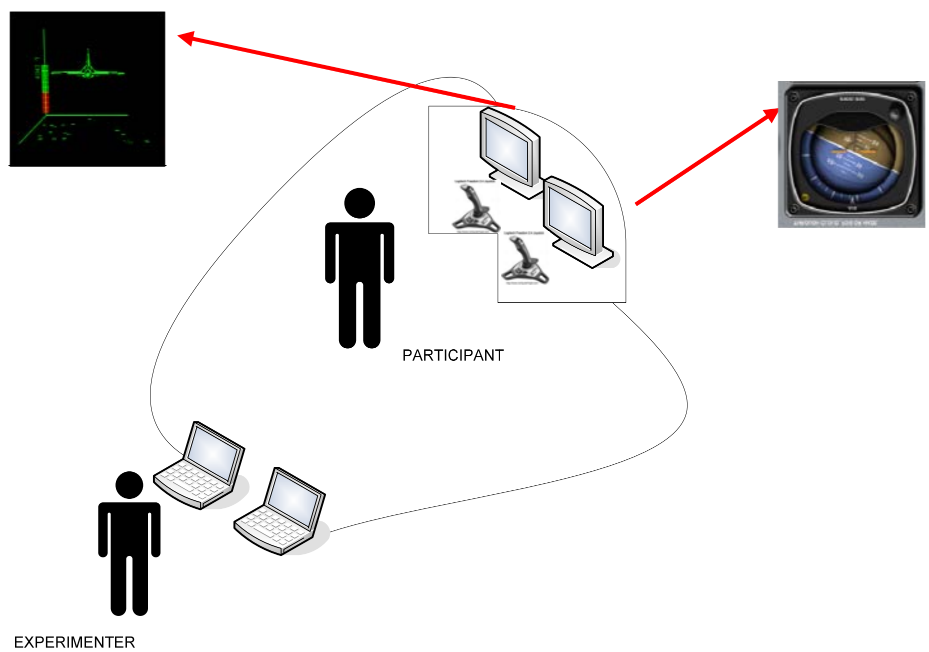

Figure 11. Instrumentation setup (task dependant respectively)

When the participant finished the second experiment block, he/she was asked to fill out the post-experimental questionnaire. This finished the

experimental session for this subject. The detailed experiment is laid out in the experiment protocols (Appendix B). A pilot study was conducted with four volunteer participants to test procedures, apparatus, and tasks (having the same level of difficulty in defining the UAV's attitude).

3. Static Spatial Awareness Experiment

The detailed procedure of this sub-experiment was documented in the experiment protocol. After the participant was led into the lab, he/she was shown all the equipment, and was instructed to sit in the operator place. The experimenter explained the use of all flight instruments and controls including the Weber Box, which was referred during the experiment as a working term to the proposed display.

The participant was allowed to fly for about 5 - 10 minutes as a brief training to become familiar with controlling the UAV where explanations for all flight instruments and controls were still provided. After the training flight, the experimenter briefed the participant for the first task (Recognition of spatial orientation of one UAV, Appendix F). Then, the instrumentation monitor or the Weber Box respectively was switched off, depending on if he begins with or without using the Weber Box.

The first trial was a test trial. The experimenter picked a set of pitch- and roll-angles from the set of possible angle pairs and transferred them into the flight simulation software. When the experimenter told him/her to start, while switching on/off respectively the monitors, he/she started to look at the instruments. When the participant said "Stop!" the experimenter measured the elapsed time and switched off the monitor. Then, the participant had to draw his/her opinion about pitch and roll into the provided schema on the evaluation sheet (Appendix F). The experiment started over with the next experiment test and a new set of pitch and roll angles until the participant finished six tasks (plus one test trial).

4. Static Spatial Awareness Experiment with Increased Workload

The detailed procedure of this sub-experiment was documented in the experiment protocol (Appendix B). As the participant was already led into the lab,

and was shown all equipment, while sitting in front of the 17” monitor he/she had only to perform the exact static spatial awareness experiment while this time he/she was asked to operate two UAV’s (increased workload).

5. NASA-TLX over Increased Workload

The NASA-TLX (Task Load index) was scored for each participant as follows. First, the number of times each factor was circled in the top portion was counted to determine the weight for that factor. The total number of weights summed to 15. Second, a scoring template was made with the subscales divided into 20 equal portions, and that template was lined up behind each participant’s TLX sheet. The numbered portion in which the participant’s mark intersected the line determined the score for the subscales. In cases where the mark appeared exactly on the line dividing the sections, the higher number was given. In addition, in cases where the mark did not touch the line, a mark was extrapolated, although in most cases the majority of the mark was in the section assigned. In cases where the participant had written a checkmark or an “x,” the corner of the check or intersection of the lines was taken as the mark, and the section in which that appeared was the score assigned. Finally, for scales in which the participant had not marked the subscale, the mean of the other scores was substituted. For each factor, the weight was multiplied by the score on the subscale to get the factor score. Finally, the factor scores were added together and that sum was divided by the number of weights, which were usually 15. This number was the total workload score.

C. PARTICIPANTS

The participants were randomly assigned from the twenty students of the NPS who volunteered for the study. All of the participants were male. Nine participants had a strong aviation background (1 helicopter pilot, 8 fighter-jet pilots). The mean age of the pilots group was 31 (range: 27 to 40) and the average flight experience was flight hours (range: 60 to 2500). The mean age of the group of non-pilots was 35 years (range: 27 to 39).

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V. DATA ANALYSIS

A. HYPOTHESES

1. Primary Hypotheses

The primary hypothesis states that an operator will be able to assess spatial position significantly faster and with grater accuracy using the proposed instruments (Weber Box) compared to use of the traditional instruments when measured under increased workload conditions. This hypothesis can be explored via the objective results of the static spatial awareness experiment. The measured time it takes a participant to assess a particular spatial situation indicates the participant's ability to create a mental model of the current spatial situation. The measured angular errors (for pitch and roll) from the given spatial orientation indicated the accuracy of this mental model (Weber, 2006).

The first hypothesis is that there will be a significant difference in the time required to assess the situation, that is, delta time= time (proposed design) – time (traditional design). The second hypothesis states that participants this time difference also will be true in the increased workload condition. We derive the null-hypothesis that there is no proportional difference between the orientation times of the two designs under an increased workload. Hence, the null-hypothesis H_0 is: $\mu_D = [\mu_2 - \mu_1]$ and $\mu_D = 0$, and therefore $\beta_1 = 0$, that is, the slope of the linear regression model is zero. The alternative hypothesis is that the orientation time using the proposed design is proportionally shorter than using the traditional design under increased workload. Hence, H_a is: $\mu_D < 0$, and therefore $\beta_1 < 0$, that is, the slope of the linear regression model is negative.

2. Secondary Hypothesis

As mentioned before, the measured angular errors (for pitch and roll) from the given and therefore true spatial orientation indicated the accuracy of this mental model. Thus, our secondary hypothesis was that the angular precision of the assessed spatial situation was at least at the same level for both instrument designs under increased workload.

A negative sum of angular errors indicated a higher accuracy in the spatial awareness assessment. Equal accuracy indicates that the new design was at least as efficient as the traditional one, even while operating under an increased workload. The precision was measured in terms of angular errors in 15° steps. This means that errors within 15° were rounded to the next value. For instance an error angle of 17° would be counted as a 15° error and a 38° error would be counted as a 45° error and so on.

To determine the number of participants needed in the study, we used statistical software package JMP® version 5.1.2. In this Alpha is the significance level, in this study 0.05, and this implies willingness to accept (if the true difference between groups is zero) that 5% (alpha) of the time a significant difference will be incorrectly declared. Error Std Deviation is the true residual error and Difference to detect is the smallest detectable difference, (how small a difference you want to be able to declare statistically significant) in this study 1.4 sec. Sample Size is the total number of observations (runs, experimental units, or samples) and Power is the probability of getting a statistic that will be declared statistically significant in this study 0.85. The estimate of the number of participants was based on the results of the pilot study.

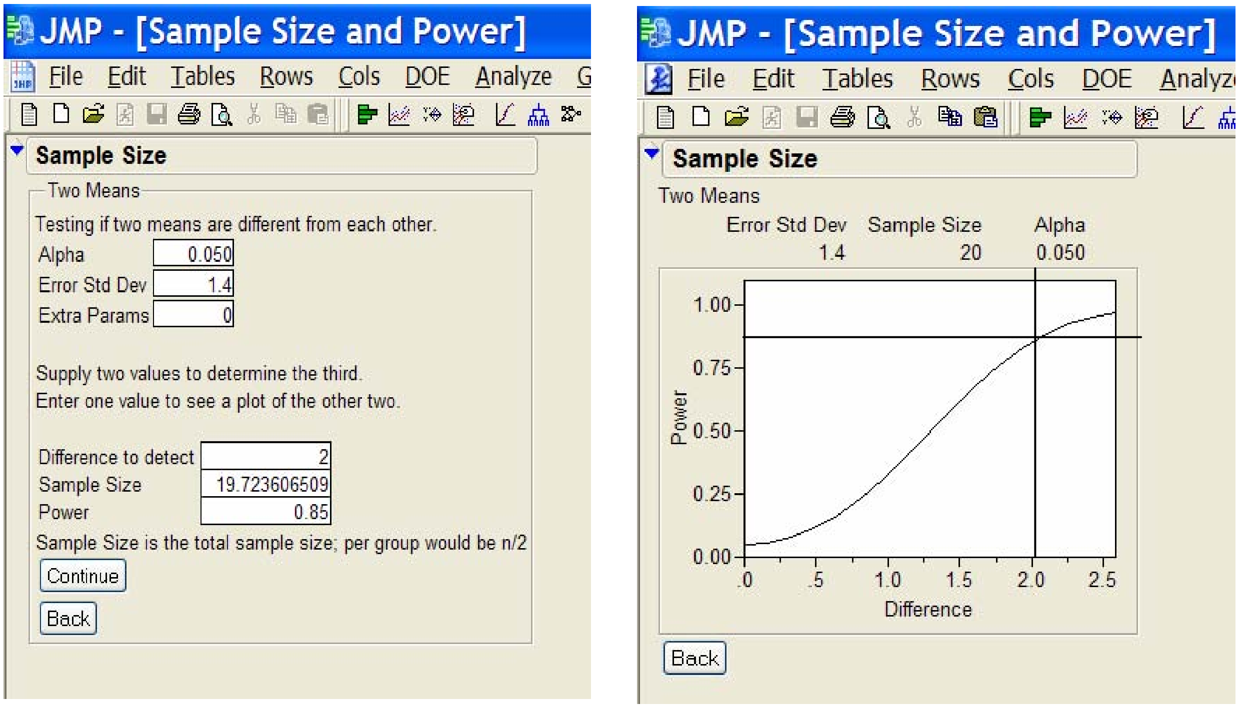


Figure 12. Statistics of required sample number

B. GENERAL DATA ANALYSIS

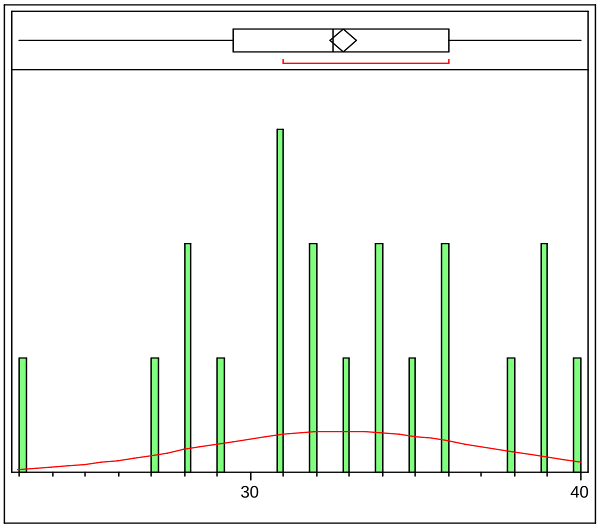
1. General Data Description

The data analysis was supported by statistical software package JMP® version 5.1.2 . The categories were:

- Orientation Time: the time a participant needs to build his/her spatial awareness in seconds.
- Pitch Error: the angular error of the estimated pitch in degrees
- Roll Error: the angular error of the estimated roll of the aircraft in degrees.
- Demographic questionnaire: age in years and flight experience in hours.
- Post-Experimental Questionnaire: the subjective assessment of the experiment.

2. Demographic Data

The non-pilot participants and the participant with aviation background have similar means of the age. The detailed statistics are shown in Figure 14.



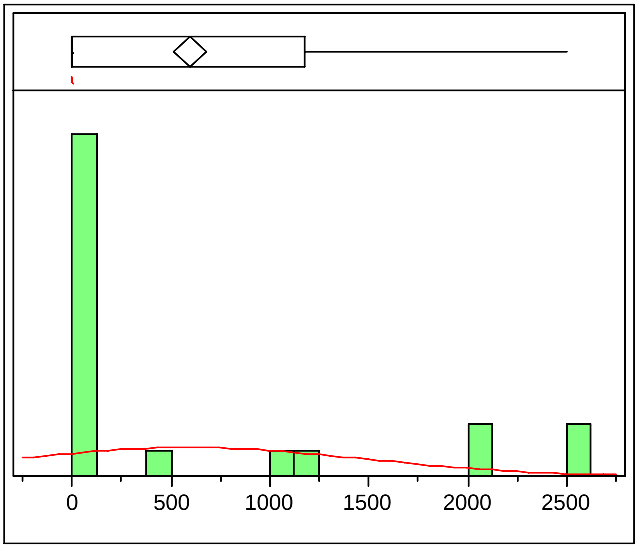
Mean	32.5
Std Dev	4.5022003
Std Err Mean	0.2005212
upper 95% Mean	33.19401
lower 95% Mean	32.40599
N	480
Sum Wgt	480
Sum	15744
Variance	19.300209
Skewness	-0.214051
Kurtosis	-0.530567
CV	13.393903
N Missing	0

Figure 13. Statistics of participant's age

The overall statistics for the age are as follows:

	Mean	**StDev**	**Minimum**	**Maximum**
Age	32.5	4.502	27	40
Pilots	35	3.887	27	39
Non-Pilots	31	3.558	27	40

Based on the statistics of the flight hours, we were able to conclude that the group of pilots can be considered as experienced. Most of the pilot participants had more than 1000 flight hours; only three of the nine had less than 1000 flight hours of experience. The detailed statistics of flight experience are shown in Figure 15.



Mean	595.5
Std Dev	902.98586
Std Err Mean	41.215477
upper 95% Mean	676.48548
lower 95% Mean	514.51452
N	480
Sum Wgt	480
Sum	285840
Variance	815383.47
Skewness	1.1688686
Kurtosis	-0.285463
CV	151.63491
N Missing	0

Figure 14. Statistics of participant's flight experience

3. Orientation Time Effects

The comparison of the means and the distribution graphs does not reveal information about individual differences between the participants but based on a Tukey – Kramer comparing means model it is revealed that the order which the participants started the experiment, meaning starting with the set A of the traditional instrument or set B of Weber Box, basically made no difference in orientation time as shown in Figure 16.

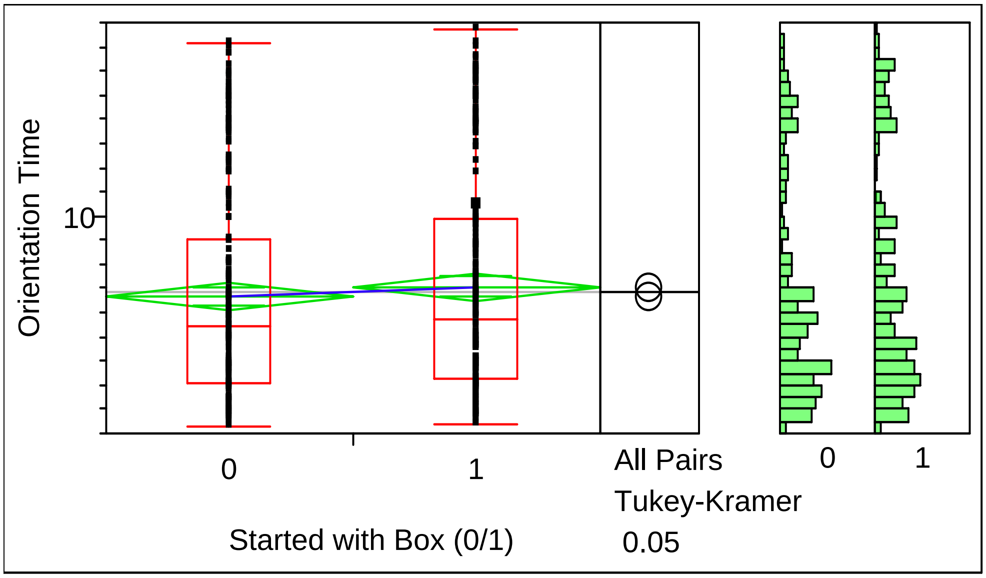


Figure 15. Linear regression on Orientation time (all participants)

Also we can state that there were no differences between the group of pilots and non-pilots. That is, pilots were slightly faster than non-pilots were (0.45 seconds). Besides the practical irrelevance of this difference, since being a pilot was a non-significant factor in the overall linear regression model, this difference has no statistical relevance as shown in Figure 16.

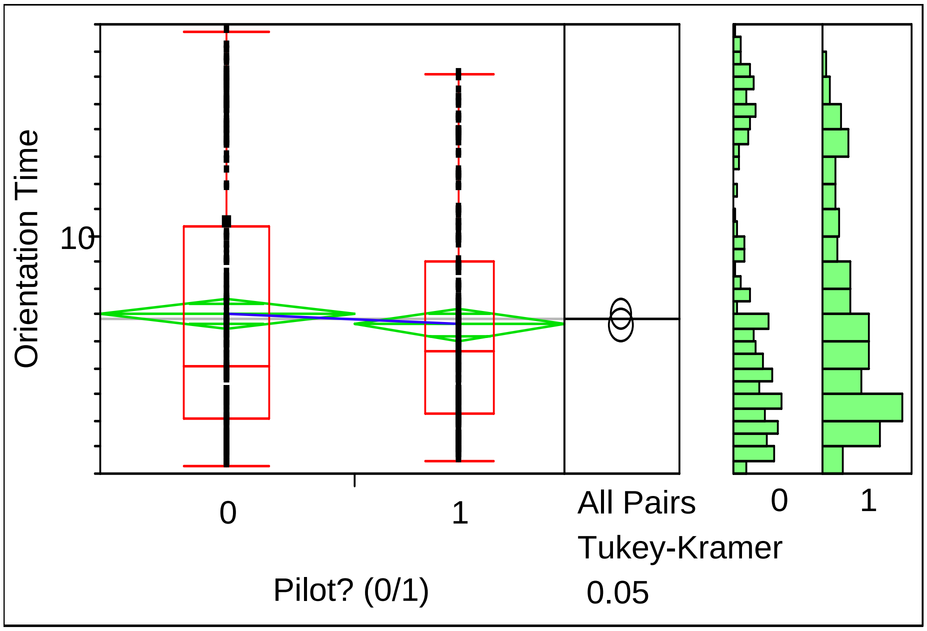


Figure 16. Linear regression on Orientation time (all participants)

When we compare orientation time for the two designs, it is clearly observable that the new design achieves much shorter orientation time. In addition we were able to determine that the variance of the data decreased by using the proposed design.

The basic evaluation by new design by orientation time, with a level of significance of $\alpha = 0.01$ by providing a test statistic with $F(1,478) = 703.1474$, $p < 0.0001$ achieved an adjusted R^2 of 0.5953, which states that this model explains 60% of the variances in the data. This was an acceptable value to establish statistical significance. Figure 18 shows the distance between the two sets of orientation time for the linear regression model. The difference in the means of the original data was negative 7.95 seconds. Thus, it took an operator on average the 3 times longer to interpret the traditional instruments.

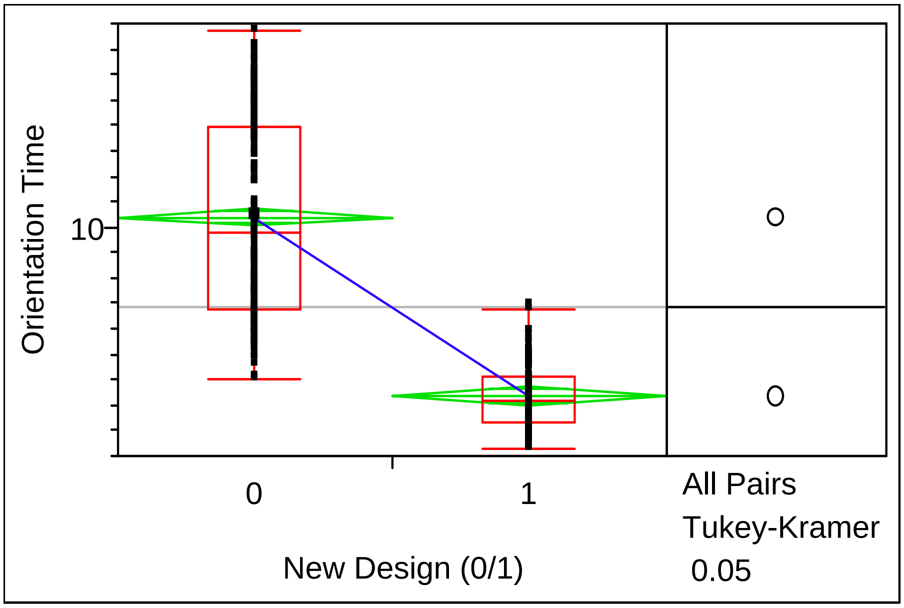


Figure 17. Linear regression on Orientation time (all participants)

The data revealed a significant difference in test times between the two set ups (operating one or two UAVs simultaneously). The basic evaluation of workload used by orientation time, with a level of significance of $\alpha = 0.01$ by providing a test statistic with $F(1,478) = 150.8302$, $p < 0.0001$ we achieved an adjusted R^2 of 0.2398, which states that this model explains over 20% of the variances in the data. Figure 18 shows the distance between the two sets of orientation time for the linear regression model.

The difference in the means of the original data was 5.05 seconds. Thus, it took an operator, on average, 2 times longer to interpret the flight instruments operating under increased workload.

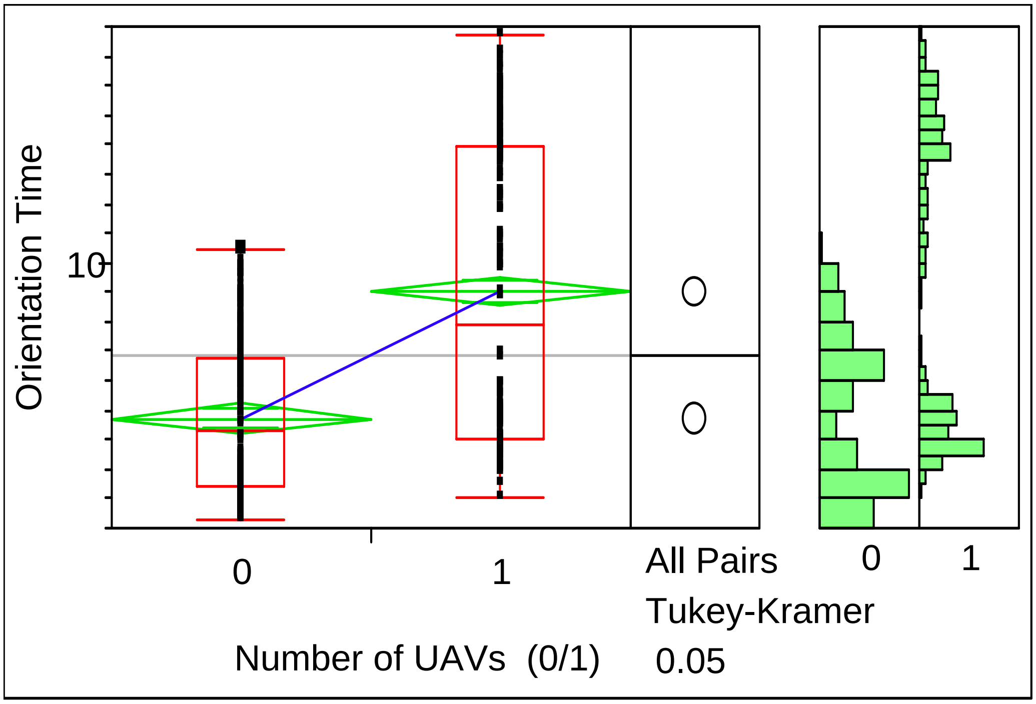


Figure 18. Linear regression on Orientation time (all participants)

We were concerned that there would be a learning effect present because participants executed 6 tasks per set up, and it is reasonable to expect that they might acquire proficiency as they completed more tasks. Figure 19 presents an ANOVA for task time using task number (1-6) as an independent variable. Using a t-test, there was no significant difference between times for tasks 1 through 6.

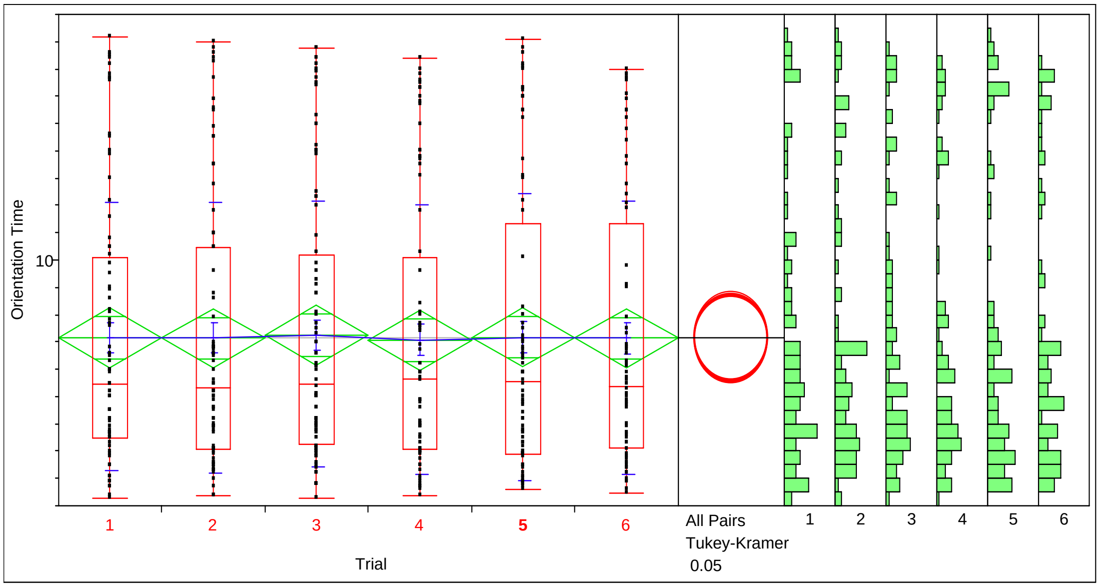


Figure 19. No learning effect as participants progressed through the tasks for (all participants)

4. General Statistical Methodology

To investigate the influences of the designs on orientation time, we decided to conduct a multiple regression analysis. First, we conducted a stepwise regression analysis (full factorial) to eliminate factors that were not influential in our model. The regression model that we are developed associates the average response to the decision factors. We began by using only main effects to get an idea of the impact of these factors alone on our model. We developed the main-effects model using the mixed stepwise function in JMP. This function uses alternating forward and backward steps, allowing terms to enter the model on the forward step and leave the model on the backward step, based on a significance level for each. For our model we allowed terms to enter the model at a significance of .25 and removed terms with significance less than .01. The potential predictors were workload and instrument design as the main suspected factors, and aviation experience (pilot or not), order of presentation and participant's age. The participants were handled as a blocking factor for the regression model. The response variables were orientation time, and pitch and roll error time. For the response variable orientation time only the display design and the workload had significant influence as a predictor variable for all response

variables with F (5,475) = 1303.975, p < 0.000 and F (5,475) = 652.783, p < 0.000 respectfully. However, the graph showed that the display design contributed the most with an R^2=0.83 while the workload explained the data with an R^2=0.25. We conducted stepwise regression for the rest of the response variables with similar results.

Stepwise Fit

Response: Orientation Time

Stepwise Regression Control

Prob to Enter 0.250
Prob to Leave 0.100
Direction: Forward
Rules: Combine

Current Estimates

SSE	DFE	MSE	RSquare	RSquare Adj	Cp	AIC
588.45792	469	1.2547077	0.9499	0.9489	9.3789556	119.7853

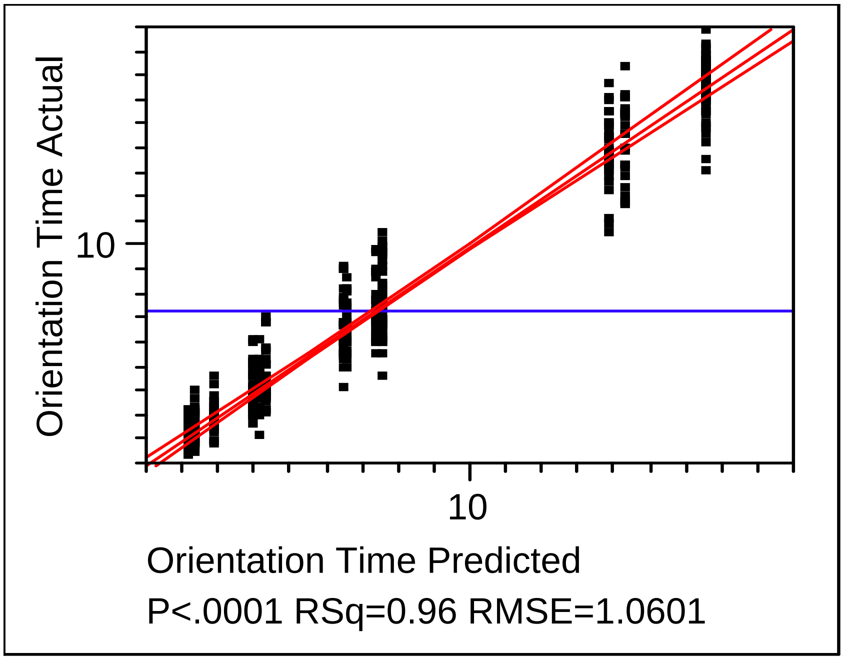
Lock	Entered	Parameter	Estimate	nDF	SS	F Ratio	Prob>F
☑	☑	Intercept	7.14309099	1	0	0.000	1.0000
☐	☑	Pilot? (0/1){1-0}	-0.3295068	4	332.2913	66.209	0.0000
☐	☑	New Design (0/1){1-0}	-3.7336862	5	8180.536	1303.975	0.0000
☐	☑	Pilot? (0/1){1-0}*New Design (0/1){1-0}	0.50272109	2	201.2752	80.208	0.0000
☐	☑	Started with Box (0/1){0-1}	-0.168091	3	22.92685	6.091	0.0005
☐	☐	Pilot? (0/1){1-0}*Started with Box (0/1){0-1}	0	1	0.222862	0.177	0.6739
☐	☑	New Design (0/1){1-0}*Started with Box (0/1){0-1}	0.07451956	1	2.638595	2.103	0.1477
☐	☐	Pilot? (0/1){1-0}*New Design (0/1){1-0}*Started with Box (0/1){0-1}	0	2	0.29674	0.118	0.8889
☐	☑	Number of UAVs (0/1){0-1}	-2.3873172	5	4095.26	652.783	0.0000
☐	☑	Pilot? (0/1){1-0}*Number of UAVs (0/1){0-1}	0.4122449	2	162.3342	64.690	0.0000
☐	☑	New Design (0/1){1-0}*Number of UAVs (0/1){0-1}	1.47148569	2	1181.374	470.777	0.0000
☐	☑	Pilot? (0/1){1-0}*New Design (0/1){1-0}*Number of UAVs (0/1){0-1}	-0.4163931	1	82.3917	65.666	0.0000
☐	☑	Started with Box (0/1){0-1}*Number of UAVs (0/1){0-1}	-0.1201828	1	6.863046	5.470	0.0198
☐	☐	Pilot? (0/1){1-0}*Started with Box (0/1){0-1}*Number of UAVs (0/1){0-1}	0	2	0.223026	0.089	0.9153
☐	☐	New Design (0/1){1-0}*Started with Box (0/1){0-1}*Number of UAVs (0/1){0-1}	0	1	1.660254	1.324	0.2504
☐	☐	Pilot? (0/1){1-0}*New Design (0/1){1-0}*Started with Box (0/1){0-1}*Number of UAVs (0/1){0-1}	0	5	4.254306	0.676	0.6420

Step History

Step	Parameter	Action	"Sig Prob"	Seq SS	RSquare	Cp	p
1	Pilot? (0/1){1-0}*New Design (0/1){1-0}*Number of UAVs (0/1){0-1}	Entered	0.0000	11141.97	0.9480	21.588	8
2	Started with Box (0/1){0-1}*Number of UAVs (0/1){0-1}	Entered	0.0004	20.28825	0.9497	9.4746	10
3	New Design (0/1){1-0}*Started with Box (0/1){0-1}	Entered	0.1477	2.638595	0.9499	9.379	11

Figure 20. Stepwise regression analysis for orientation time

The regression model enables us to reject the H_0 at a level of significance of α = 0.01 by providing a test statistic with F(15,464) = 726.8835 (sufficiently large), p < 0.0001, with R^2 of 0.9591.



RSquare	0.959181
RSquare Adj	0.957861
Root Mean Square Error	1.060053
Mean of Response	7.282292
Observations (or Sum Wgts)	480

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	15	12252.117	816.808	726.8835
Error	464	521.402	1.124	Prob > F
C. Total	479	12773.519		<.0001

Figure 21. Graph explaining test time as a result of the independent variables

A more extensive analysis allowed us to conduct an interpretation with the Prediction profiler (displays prediction traces for each *X* variable. A *prediction trace* is the predicted response as one variable is changed while the others are held constant at the current values) in JMP where an interaction plot is the evidence of interaction, showed by nonparallel lines. The importance of a factor can be assessed to some extent by the steepness of the prediction trace. If there are interaction effects or cross-product effects in the model, the prediction traces can shift their slope and curvature as you change current values of other terms. If there are no interaction effects, the traces only change in height, not slope or shape. We can notice through all the different combinations, that among the

following idependent variables only the instrument design (new design (0/1)) and workload (number of UAVs(0/1)) do shift the slope and change the values of the terms, with the first having the most influence.

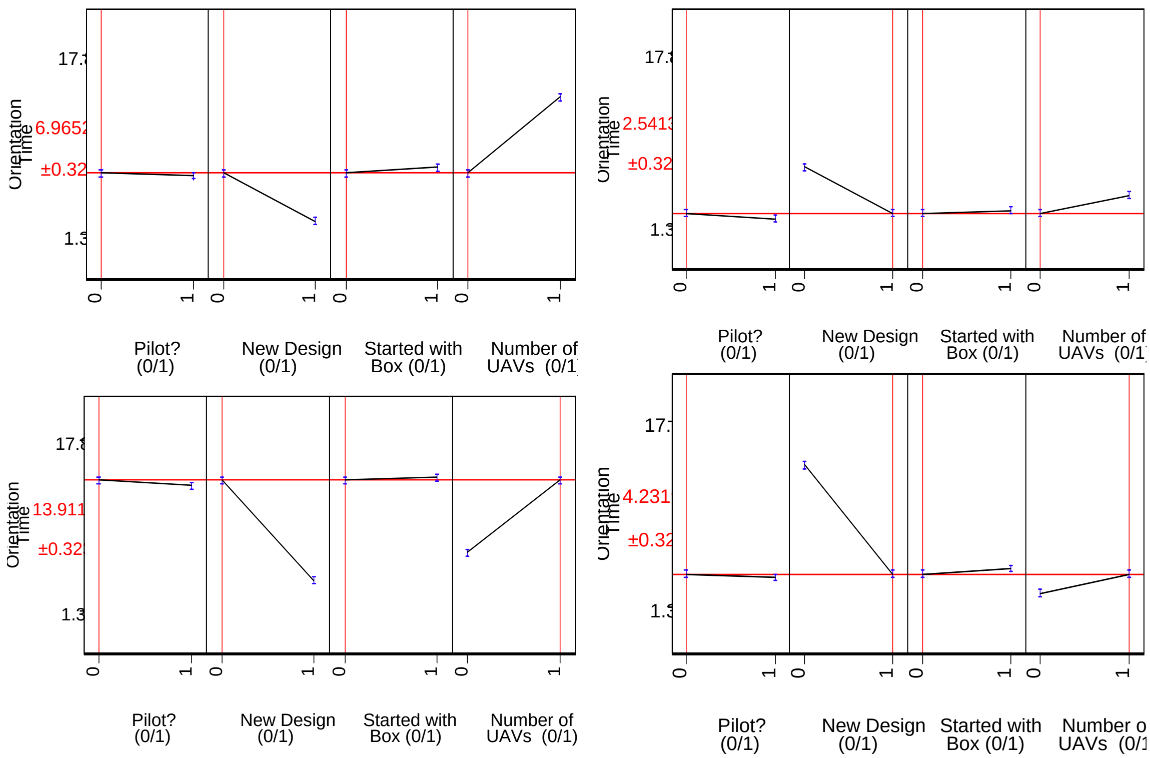


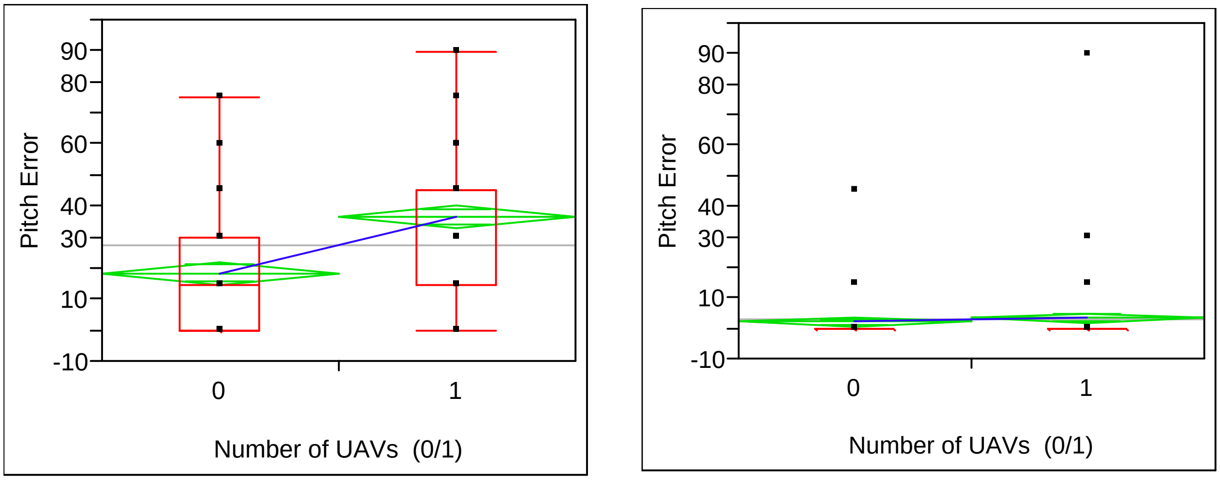
Figure 22. Prediction profiler analysis for orientation time

5. Angular Pitch and Roll Errors Effects

The statistics of the pitch and roll errors show that participants were able to judge the current pitch angle of the UAV more accurately using the new design and as expected they performed even better while operating under an increased workload as it is shown in the Figure 23 and 24 (following). The box-plot of the data suggests a significant reduction of the pitch errors by the new design which is even more evident while operating under an increased workload.

Although the data revealed that there was no significant difference in errors between the two set ups (operating one or two UAVs simultaneously). The difference in the means of the original data for pitch and roll by design (0/1) was 18.25^{o} and 01.37^{o} and 06.25^{o} and 0.7 respectively. Thus, an operator on average

made the same proportional errors operating the new design under an increased workload while he increased the errors operating with the traditional instruments set up.



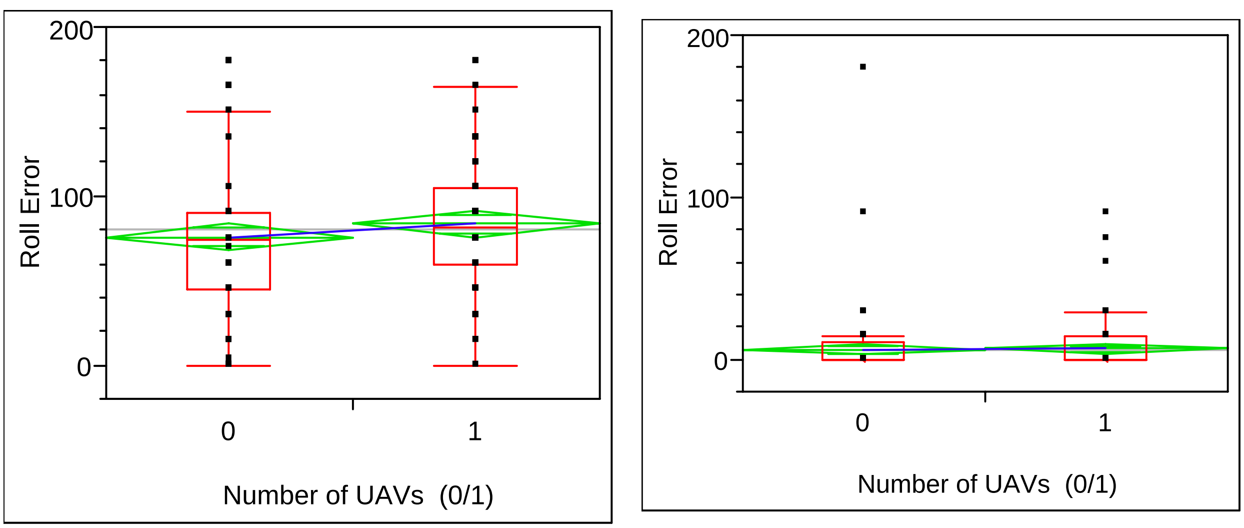
Traditional design

Level	Number	Mean	Std Error
0	120	18.5000	1.9711
1	120	36.7500	1.9711

New design

Level	Number	Mean	Std Error
0	120	2.25000	0.82927
1	120	3.62500	0.82927

Figure 23. Linear regression for pitch time by design (0/1)



Traditional design

Level	Number	Mean	Std Error
0	120	76.3667	4.0714
1	120	84.1250	4.0714

New design

Level	Number	Mean	Std Error
0	120	6.37500	1.5506
1	120	7.00000	1.5506

Figure 24. Linear regression for roll time by design (0/1)

We can notice through all the different combinations of independent variables, only the instrument design (new design (0/1)) and workload (number of UAVs(0/1)) do shift the slope and change the values of the terms, with instrument design having the mostinfluence.

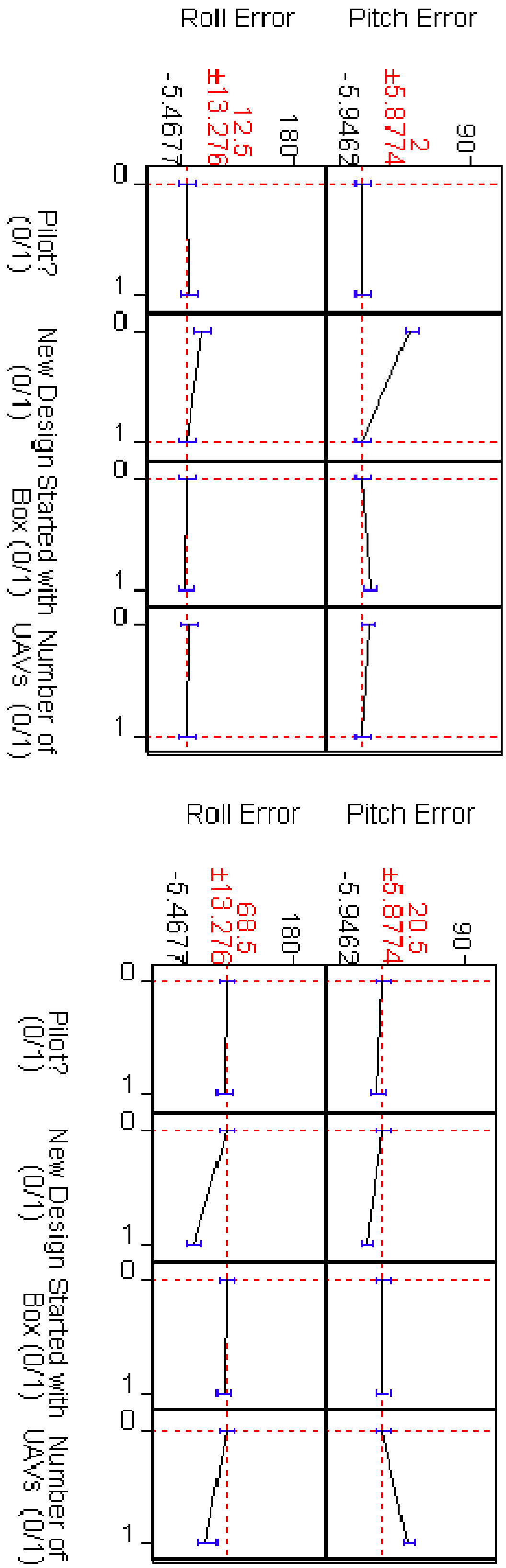


Figure 25. Prediction profiler analysis for pitch and roll time

The distribution of the angular pitch and roll error can be assumed as normal. However, the box-plots show some outliers, which we decided to keep in the dataset. These outliers represent, in our opinion, human errors, which may occur and hence were not an abnormality. In particular angular error can lead in many cases to serious aviation mishaps (Previc et al., 2004).

The error in judging their own roll angle was mastered by pilots and non-pilots with an equal level of accuracy and a similar variance of the data. Pilots were slightly better in estimating the pitch and roll of the UAV.

6. Post-Experiment Questionnaires

The analysis of the NASA-TLX questionnaire (of the subjective workload of all the operators as a group) showed a significantly higher workload in the increase workload setup. When analyzed by the standard of aviation experience, results indicated that those with aviation experience reported significant differences in workload between setups, while those without aviation experience reported more significant differences. This indicates that the operators' subjective workload of operators' increases with the addition of secondary tasks, but this may vary with aviation experience. The mean NASA-TLX scores are presented in Table 1.

Table 1. Mean Subjective Workload Scores

	1 UAV TLX score	**2 UAVs TLX score**
All participants	62.88	65.48
Pilots	58.24	61.38
Non pilots	64.82	66.53

The difficulty of the tasks was experienced as slightly difficult to somewhat easy to accomplish. The answers of the post-experimental questionnaires showed a strong tendency towards the preference of the Weber Box. However, the questionnaires show that most participants (over 80%), pilots and non-pilots,

appreciated the proposed design and felt supported in their spatial orientation tasks more than using the traditional setup (basic T). The answers in percentages were as follows.

Table 2. Results of Post-Experiment Questionnaires - Orientation Task A

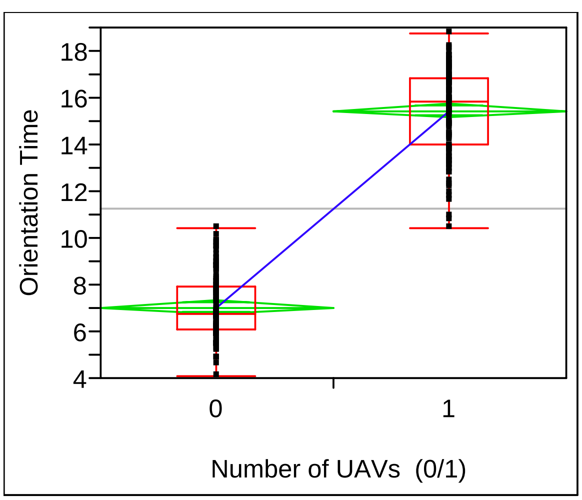
Question	Answer-Options				
In general, how do you judge the difficulty of evaluating the current attitude of the UAV?	*Very easy* **5%**	*Somewhat easy* **40%)**	*Border line* **20%**	*Somewhat complicated* **35%**	*Very difficult* **0%**
In general, how do you judge difficulty of using the traditional flight instruments for this task?	*Very easy* **0%**	*Somewhat easy* **20%**	*Border line* **20%**	*Somewhat complicated* **50%**	*Very difficult* **15%**
In general, how do you judge the difficulty of using the WEBER-Box for this task?	*Very easy* **50%**	*Somewhat easy* **50%**	*Border line* **0%**	*Somewhat complicated* **0%**	*Very difficult* **0%**
Did you feel better aware of the spatial orientation of the UAV with the WEBER-Box in comparison with the traditional flight instruments?	*Much less* **0%**	*Somewhat less* **0%**	*Border line* **0%**	*Somewhat more* **25%**	*Much more* **75%**
Did having the WEBER-Box increase or decrease your monitoring demands in comparison with the traditional flight instruments?	*Greatly decreased* **45%**	*Somewhat decreased* **50%**	*Unaffected* **5%**	*Somewhat increased* **0%**	*Greatly increased* **0%**
Did having the WEBER-Box increase or decrease your overall workload in comparison with the traditional flight instruments?	*Greatly decreased* **45%**	*Somewhat decreased* **50%**	*Unaffected* **5%**	*Somewhat increased* **0%**	*Greatly increased* **0%**
Did having the WEBER-Box increase or decrease your overall frustration level (irritate, stress, insecure) in comparison with the traditional flight instruments?	*Greatly decreased* **70%**	*Somewhat decreased* **25%**	*Unaffected* **5%**	*Somewhat increased* **0%**	*Greatly increased* **0%**
How would you characterize your Computer Skills	*None* **0%**	*Fair* **0%**	*Average* **10%**	*Good* **70%**	*Excellent* **20%**
How much experience do you have with computer games?	*None*	*Fair*	*Average* **30%**	*Good* **60%**	*Excellent* **10%**

VI. CONCLUSIONS

A. OVERALL ASSESSMENT OF THE STATISTICAL RESULTS

The purpose of the current study was to assess both subjective workload and associated performance decrements while operating the proposed display design versus the traditional instrument design (Weber, 2006). Specifically, the focus was to assess the relationship between a subjective workload and various objective measures of performance both with and without the introduction of a secondary task involving operating one or two UAVs.

The statistical analysis supported the proposed design in all aspects. The design seemed to sustain remarkably well the spatial awareness in 3D orientation tasks even under high workload conditions. Time to assess a spatial situation decreases significantly, with the new display, whereas accuracy of this spatial judgment at least maintains its level. Judgment errors were minimized and the extreme errors were almost eliminated. Figure 26 shows the level of increased orientation time as workload increases while operating the traditional design. The steeper the line shows, the more influence is of the added workload. It seems that the pilots were not able to improve their speed better than non-pilots but further analysis revealed that was due to increased accuracy.



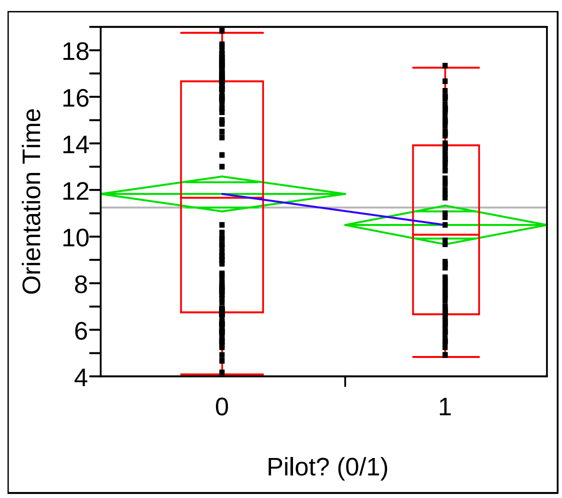


Figure 26. Linear regression for orientation time by design (traditional)

Figure 27 shows the level of increased orientation time as the workload increases while operating the proposed design. The added workload is more influential when the line is steeper. It seems that the pilots were able to improve their speed better than non-pilots did.

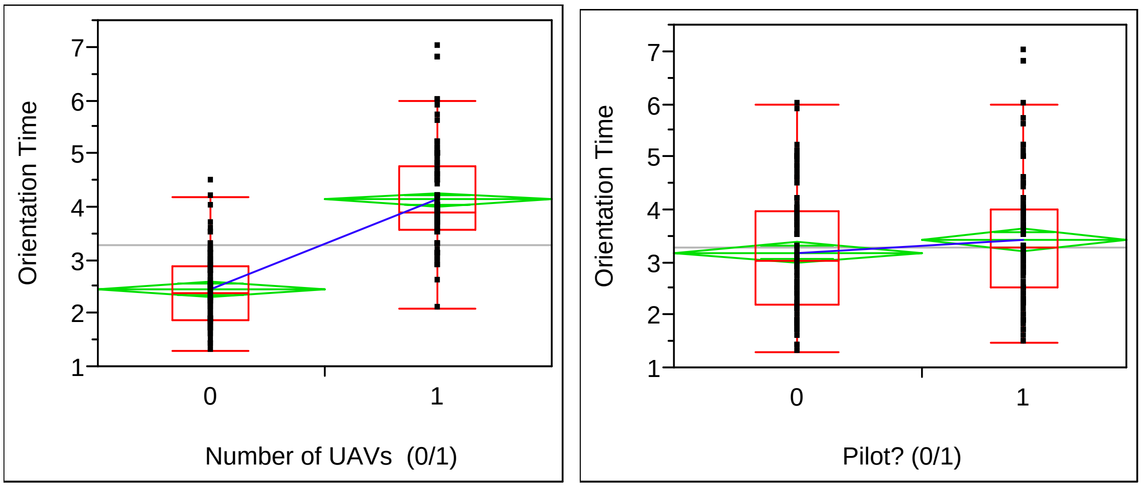


Figure 27. Linear regression for orientation time by design (proposed)

It was surprising that pilots and non-pilots were so similar. The differences were minor. We explain this phenomenon with the character of the tests, which were not overly demanding. Another aspect might be that the underlying cognitive processes are basically the same whether operating the Weber Box design (while it was almost twice as big) or operating the setup with the traditional instruments. Thus, everybody took equal advantage out of the proposed design.

The statistics of the values were as follows:

Traditional design

Source	DF	F Ratio	Prob > F
Number of UAVs (0/1)	1	1655.561	<.0001
Error	238		
C. Total	239		

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
0	120	7.0550	0.14624	6.767	7.343
1	120	15.4700	0.14624	15.182	15.758

Proposed design

Source	DF	F Ratio	Prob > F
Number of UAVs (0/1)	1	295.2498	<.0001
Error	238		
C. Total	239		

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
0	120	2.45667	0.06958	2.3196	2.5937
1	120	4.14750	0.06958	4.0104	4.2846

The proposed study was conducted to support operators of UAVs in extreme situations - increased workload. The main goal was to provide an intuitive way to improve the level of spatial awareness in ambiguous conditions. In particular, it utilizes the principle of the mental model by introducing an exocentric view on a virtual avatar in an abstract three-dimensional virtual world while the participants were subjected to increased workload. This positive picture was supported by the comments and post-experimental questionnaires. The majority of the participants found the “WEBER-Box” to be very helpful and intuitive to understand, especially under increased workload where the response time was proportionally smaller. The participants felt that the “WEBER-Box” improves their spatial awareness and made it easier to accomplish their tasks. The following Figure 28 depicts JMP’s partition platform which enables us to systematically analyze data sets and to discover unsuspected or unknown relationships by visualizing a successive tree of partitions according to a relationship between the X and Y variables. It finds a set of cuts or groupings of X values that best predict a Y value by exhaustively searching all possible cuts or groupings, recursively. Thus we can easily see, achieving R^2 of 0.959, the impact of the design as opposed to the increased workload. Similar partition model were found for roll and pitch errors indicating the superiority of the Weber box.

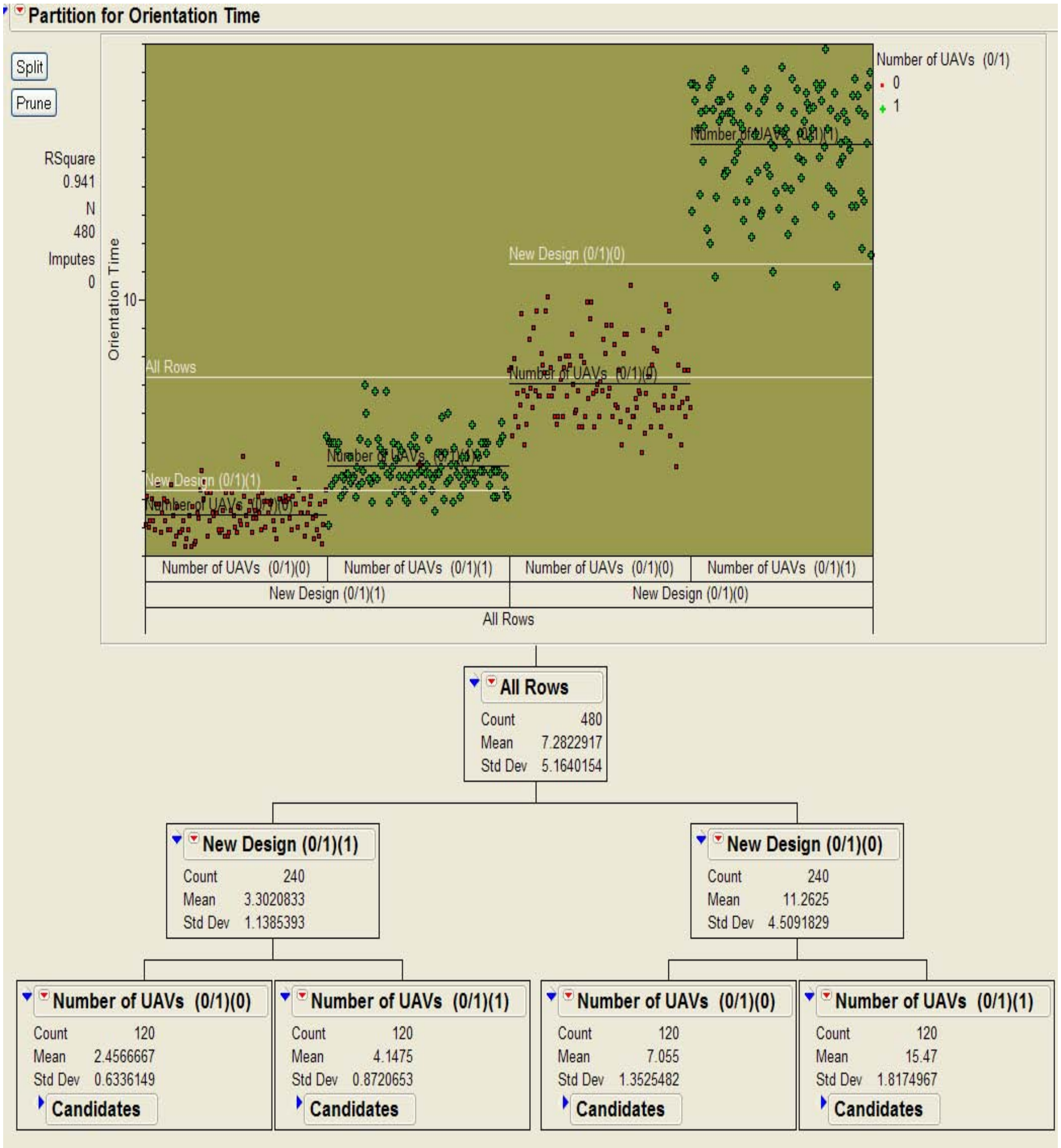


Figure 28.   Partition for orientation time

Many of the underlying interactions and effects are not completely investigated. Questions about design improvements and practical applications need to be answered as well. However, by applying human-centered design principles we were able to design an efficient tool to support spatial awareness in 3D-orientataion tasks. Our data clearly reveals that the nontraditional design

Weber box (Weber, 2006) yielded superior performance to the traditional one. The design was accepted and appreciated by both the pilot and the non-pilot participants and was proven beneficial especially under complex tasks with increased workload.

B. FUTURE APPLICATIONS

We can see applications of the WEBER Box design in all major fields of aviation. Since this design is intuitively understandable, it might help flight students to understand traditional flight instruments. Thus, integration into traditional flight instruments or even to add flight instruments to WEBER Box might be beneficial. Because this study's major goal was to implement, test and evaluate a novel display design (Weber, 2006), it turned out that more questions were formed than it answered. Foremost questions that are open to future research are about design improvements and the influence of alternations and simplifications. Questions may include:

- What is the optimal size?
- How much can we simplify the aircraft model?
- Should we integrate scales to make it a complete flight instrument and given that, how much information and graphics can be simplified without degrading the outcome?
- Are the principles of the WEBER Box applicable to other fields (car driving, under water robots, etc.)?
- Is the WEBER Box useful for training purposes as pilot training, UAV ground control systems operators, etc.?
- How much an even more increased workload environment (i.e. auditory tasks) will affect performance and spatial attitude definition?

Other research might investigate the potential of the current design, the regarding the altitude representation and the various possible implementations of warning at extreme situations.

APPENDIX A. IRB APPLICATION AND APPROVAL

Anthony Ciavarelli, Ed.D.
Modeling Virtual Environment and Simulation Department
Watkins Hall
Naval Postgraduate School
Monterey, California 93943

831-656-2191
DSN: 756-2191
Fax: 831-656-2595
ACiavarelli@nps.edu

To: Protection of Human Subjects Committee

Subject: **Application for Human Subjects Review for Use of Avatars to Support and Enhance Spatial Awareness in 3D-Orientation-Tasks**

1. Attached is a set of documents outlining a proposed experiment to be conducted over the year to support the thesis of Lieutenant Colonel Dimitrios Myttas, GR.

2. We are requesting approval of the described experimental protocol. An experimental outline is included for your reference that describes the methods and measures we plan to use.

3. We include the consent forms, privacy act statements, questionnaires, and briefing forms we will be using in the experiment.

4. We understand that any modifications to the protocol or instruments/measures will require submission of updated IRB paperwork and possible re-review. Similarly, we understand that any untoward event or injury that involves a research participant will be reported immediately to the IRB Chair and NPS Dean of Research.

Anthony Ciavarelli

<table>
<tr><td>APPLICATION FOR
HUMAN SUBJECTS REVIEW (HSR)</td><td>HSR NUMBER (to be assigned)</td></tr>
<tr><td colspan="2">PRINCIPAL INVESTIGATOR(S) (Full Name, Code, Telephone)
Anthony Ciavarelli, Ed.D., Monterey, CA 93943, Phone: 831 656-2191
(Thesis LtCol Dimitrios Myttas, GR)</td></tr>
<tr><td colspan="2">APPROVAL REQUESTED [X] New [ ] Renewal</td></tr>
<tr><td colspan="2">LEVEL OF RISK [ ] Exempt [ ] Minimal [ ] More than Minimal
Justification: 3D-Virtual Environment (flight simulator software)</td></tr>
<tr><td>WORK WILL BE DONE IN (Site/Bldg/Rm)
NPS, Watkins Hall, Rm 212B</td><td>ESTIMATED NUMBER OF DAYS TO COMPLETE
10</td></tr>
<tr><td>MAXIMUM NUMBER OF SUBJECTS
30</td><td>ESTIMATED LENGTH OF EACH SUBJECT'S PARTICIPATION
2 hours</td></tr>
<tr><td colspan="2">SPECIAL POPULATIONS THAT WILL BE USED AS SUBJECTS
[ ] Subordinates [ ] Minors [X] NPS Students [ ] Special Needs (e.g. Pregnant women)

Specify safeguards to avoid undue influence and protect subject's rights: none</td></tr>
<tr><td colspan="2">OUTSIDE COOPERATING INVESTIGATORS AND AGENCIES

- none-
[ ] A copy of the cooperating institution's HSR decision is attached.</td></tr>
<tr><td colspan="2">TITLE OF EXPERIMENT AND DESCRIPTION OF RESEARCH (attach additional sheet if needed). Methodology attached</td></tr>
<tr><td colspan="2">I have read and understand NPS Notice on the Protection of Human Subjects. If there are any changes in any of the above information or any changes to the attached Protocol, Consent Form, or Debriefing Statement, I will suspend the experiment until I obtain new Committee approval.

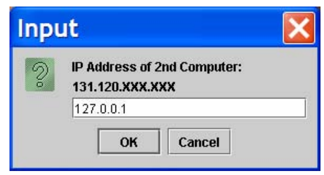
SIGNATURE____

DATE__________________</td></tr>
</table>

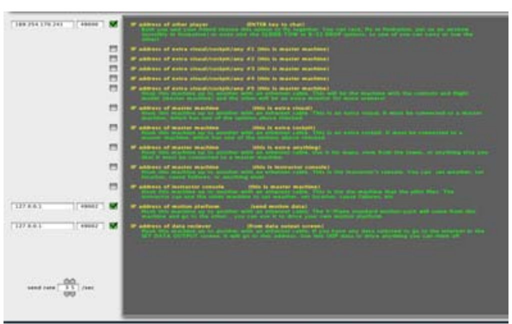
APPENDIX B. EXPERIMENT PROTOCOL

EXPERIMENTAL WORKSTATION ENVIRONMENT STARTUP

1. Switch on the personal computer (laptop), and the extra 17” TFT monitor on the experimenter desk.
2. Login at the computer by pressing ALT_DEL_CTRL. Let the password empty and press ENTER.
3. Open the “Local Area Network” icon in the task bar using the RIGHT mouse button.
4. In the following menu chose STATUS, click on the SUPPORT-tab and write down the IP-address (e.g. 131.120.151.6), or just type “ipconfig” at command prompt.
5. Start on the desktop the following programs by clicking the icons twice by the mouse:
    a. “UDP Reflector” => type in the dialog box the IP-address of the computer und press ENTER
    b. “X-Plane Experiment”



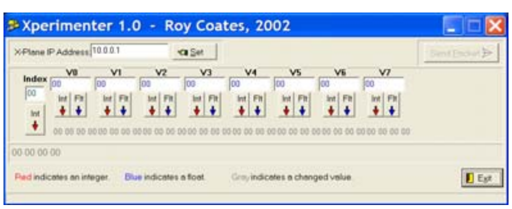
6. After “X-Plane” started,



⇨ choose menu “Location” => select “Place Aircraft by Airport” => chose “Twenty-nine Palms EAF” => click “Go to this Airport”
⇨ choose menu “Files” => select “Load Scenarion” => click on “Experiment.sit”
⇨ wait until the situation is loaded, than hit the “P” button of the keyboard to pause the simulation
⇨ make sure that the following values have been typed (127.0.0.1 - localhost).

Start the WEBER BOX

1. On the computer double click on the icon ”Start Weber Box” icon -> in the window type in for the UDP port: 49002 and 1.0 for the speed. Now the WEBER-Box should appear. The experimenter can drag it to the 17” monitor for all experiments which demand the WEBER-Box.
2. Double-click on the icon “Experimenter” to start the input consol.



⇒ Type in the field “IP-Address” the number 131.120.150.248 and click the button “set” right to the input field
⇒ Type in the filed “ID” the number 16 and click the button “int” below the field
⇒ Insert the different values (V0, V1- Pitch, Roll) and click the button “flt” below the field

PRE-EXPERIMENT PROTOCOL

- Check if all forms are prepared and signed by the experimenter and the principle investigator
- Escort participant to peroration desk
- Administer Initial Questionnaires
    - Hand out the written experiment objectives and the experiment introduction.
    - Present Institutional "IRB Participant Consent Form", the "Minimal Risk Consent Statement", the "Privacy Act Statement" and let it sign by the participant.
    - Check if the participant's ID number is noted on every page of the initial questionnaire and present it and let the participant sign it.
- Request if the participant has any further questions

SPATIAL AWARENESS EXPERIMENT PROTOCOL

- Participant is led to the Experimental workstation and shown all equipment.
- Participant is instructed to sit in front of the operator computer.
- Experimenter explains all flight instruments and controls incl. the Weber Box.
- Experimenter starts the training scenario (the aircraft is airborne on a safe altitude and attitude) and allows the participant to fly for about 10 minutes. In this time the experimenter provides any help regarding explanations of the use of the flight instruments and controls. He <u>must not</u> refer to any of the later experiment tasks.
- Experimenter gives the participant the briefing for the first task (Recognition of spatial orientation of the aircraft) and makes participant familiar with the procedures. He is now advised to read the task instructions for this task.
- Experimenter switches off the instrumentation monitor or switches off the Weber Box respectively, depending if he begins with or without using the Weber Box.
- Experimenter asks participant if he/she understands everything and if he may start the experiment
- The first trial is a test trial; the test-trial sheet has to be used for it.
- Experimenter:
    - starts spatial awareness scenario
    - prepares the stop watch
- Experimenter: Switches off the monitor, and determines a set of pitch- and roll-angles from the task sheet "Test A" ("Test B" for the 2nd set of experiments) by
    - Typing the angle values in degrees in field "00" for the pitch and field "01" for the roll and clicks on the button "flt" below the field to store the values

    - Clicks the button “Send Data Package” to transfer the values to the experimental workstation monitor
    - Observes whether the flight simulation software (X-Plane or Weber Box) reacts as expected
    - If not, he checks again all values and presses all described buttons again to store the data
- Experimenter:
    - Stands directly on the participants left side and places his left hand at the power button of the monitor and holds the stop watch in his right hand
    - Switches on the monitor and tells the participant that he may start to look at the instruments
    - In the moment the participant starts looking the monitor and at the instruments, he starts the stop watch
    - When the participant says “Stop!” he switches of the monitor and stops the stop watch at the same time
- Experimenter:
    - Let the participant draw his/her opinion about pitch and roll into the provided schema on the evaluation sheet
    - Writes the measured time into field next to the evaluation schema.
    - Experimenter starts over with the next experiment loop and a new set of pitch and roll angles until the participant finished six tasks (plus one test trial).
- Experimenter starts with the SPATIAL AWARENESS EXPERIMENT with increased workload (Operating two UAVs)

POST EXPERIMENT PROTOCOL

- Participant is allowed to have a five minutes break

- Reseat the participant and start with the 2nd block of experiments including the spatial awareness experiment and spatial awareness experiment with increased workload.

- After all tests are completed the experimenter:

    - Thanks the participant for his/her effort
    - Guides participant to a chair
    - Provides the “Post-Experiment Questionnaire” and asks participant to fill it out
    - Evaluates the angular errors of the SA-experiment and notes it down into the evaluation sheets
    - Records all results in the participant’s database.
- Thank participant for participating in the experiment.

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APPENDIX C. PARTICIPANT INFORMATION FORMS

PARTICIPANT CONSENT FORM

1. **Introduction.** You are invited to participate in a study of spatial awareness of virtual environments. With information gathered from you and other participants, we hope to prove the concept of the use of virtual avatars to support and enhance spatial awareness and improve orientation performance. We ask you to read and sign this form indicating that you agree to be in the study. Please ask any questions you may have before signing.
2. **Background Information.** The Naval Postgraduate School MOVES Institute is conducting this study.
3. **Procedures.** If you agree to participate in this study, the researcher will explain the tasks in detail. There will be two sessions with two different orientation tasks each. The execution phases will last approximately two hours total, during which you will be asked to accomplish a number of tasks related to spatial awareness while operating a virtual flight simulator software. Following the study you will be asked to fill out questionnaires during a 20-minutes rest period.
4. **Risks and Benefits.** This research involves having a participant fly a 3D virtual flight simulator software. If you have any cardiac risk factors (High blood pressure, smoking, diabetes, high cholesterol, previous heart problems), we request that you PLEASE INFORM THE EXPERIMENT ADMINISTRATOR AND YOU WILL NOT BE ABLE PARTICIPATE IN THE EXPERIMENT.
5. **Compensation.** No tangible reward will be given. A copy of the results will be available to you at the conclusion of the experiment period.
6. **Confidentiality.** The records of this study will be kept confidential. No information will be publicly accessible which could identify you as a participant.
7. **Voluntary Nature of the Study.** If you agree to participate, you are free to withdraw from the study at any time without prejudice. You will be provided a copy of this form for your records.
8. **Points of Contact.** If you have any further questions or comments after the completion of the study, you may contact the research supervisor, Dr. Anthony Ciavarelli, Ed.D., NPS Monterey, CA 93943, Phone: 831 656-1073
9. **Statement of Consent.** I have read the above information. I have asked all questions and have had my questions answered. I agree to participate in this study.

-- ---------------------------
Participant’s Signature Date

-- ---------------------------
Researcher’s Signature Date

MINIMAL RISK CONSENT STATEMENT
NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943

Participant: VOLUNTARY CONSENT TO BE A RESEARCH PARTICIPANT IN: **Use of Avatars to Support and Enhance Spatial Awareness in 3D-Orientation-Tasks**

1. I have read, understand and been provided "Information for Participants" that provides the details of the acknowledgments below.

2. I understand that this project involves research. An explanation of the purposes of the research, a description of procedures to be used, identification of experimental procedures, and the extended duration of my participation have been provided to me.

3. I understand that this project does not involve more than minimal risk. I have been informed of any reasonably foreseeable risks or discomforts to me.

4. I have been informed of any benefits to me or to others that may reasonably be expected from the research.

5. I have signed a statement describing the extent to which confidentiality of records identifying me will be maintained.

6. I have been informed of any compensation and/or medical treatments available if injury occurs and is so, what they consist of, or where further information may be obtained.

7. I understand that my participation in this project is voluntary; refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I also understand that I may discontinue participation at any time without penalty or loss of benefits to which I am otherwise entitled.

8. I understand that the individual to contact should I need answers to pertinent questions about the research is Professor Anthony Ciavarelli, Thesis Advisor, and about my rights as a research participant or concerning a research related injury is Prof. Rudy Darken, MOVES Institute Chairman or the NPS IRB Medical Advisor, LTC Eric Morgan, MC, USA, Presidio of Monterey, (831) 242-7550, eric.morgan@NW.AMEDD.ARMY.MIL

____

Signature of Principal Investigator Date

____

Signature of Volunteer Date

PRIVACY ACT STATEMENT

NAVAL POSTGRADUATE SCHOOL, MONTEREY, CA 93943
PRIVACY ACT STATEMENT

1. Purpose: Spatial cognition data will be collected to enhance knowledge, and to develop tests, procedures, and equipment to improve the development of Virtual Environments.

2. Use: Spatial cognition data will be used for statistical analysis by the Departments of the Navy and Defense, and other U.S. Government agencies, provided this use is compatible with the purpose for which the information was collected. Use of the information may be granted to legitimate non-government agencies or individuals by the Naval Postgraduate School in accordance with the provisions of the Freedom of Information Act.

3. Disclosure/Confidentiality:

    a. I have been assured that my privacy will be safeguarded. I will be assigned a control or code number, which thereafter will be the only identifying entry on any of the research records. The Researcher will maintain the cross-reference between name and control number. It will be decoded only when beneficial to me or if some circumstances, which is not apparent at this time, would make it clear that decoding would enhance the value of the research data. In all cases, the provisions of the Privacy Act Statement will be honored.

    b. I understand that a record of the information contained in this Consent Statement or derived from the experiment described herein will be retained permanently at the Naval Postgraduate School or by higher authority. I voluntarily agree to its disclosure to agencies or individuals indicated in paragraph 3 and I have been informed that failure to agree to such disclosure may negate the purpose for which the experiment was conducted.

    c. I also understand that disclosure of the requested information, including my Social Security Number, is voluntary.

____

Name, Grade/Rank (if applicable)
[Please print]

____

Signature of Volunteer Date

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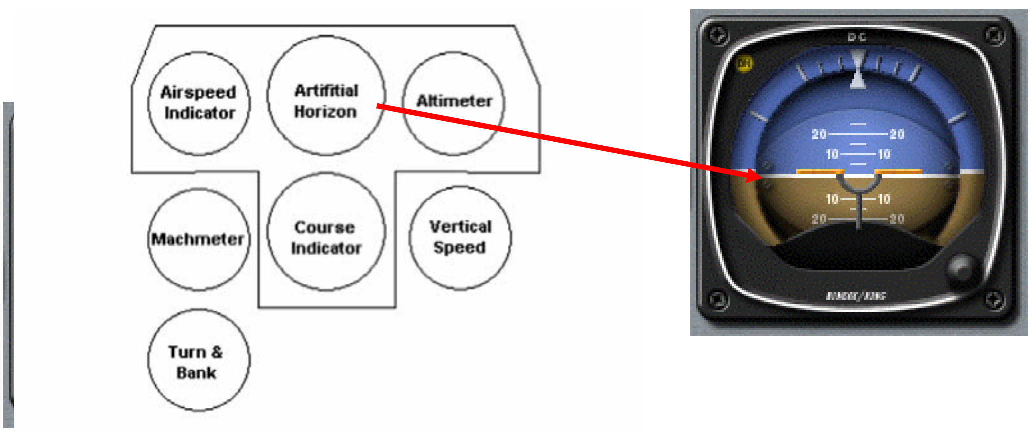
APPENDIX D. TASK DESCRIPTIONS

Spatial Orientation

Background

Unmanned air vehicles are nowadays seen as an area of great importance in the aerospace industry. An essential part of these aeronautical systems is the ground control station or GCS. This is the unit on the ground that sends and receives signals from one or several airborne units. These are normally very complicated systems that require many personnel. There is a general accepted way of thinking that says there are six main instruments, which give an overall picture of the aircrafts flight condition. These six primary instruments are airspeed indicator, altimeter, artificial horizon, direction indicator, vertical speed indicator and turn and bank indicator. It is important to group these instruments in the right way in order to let the pilot clearly interpret the situation without confusion. Over the years many different layouts have been experimented; however there is now one accepted layout, which all modern airplanes adopt. This is known as the basic T.



Artificial Horizon

This indicates the pitch, bank and heading attitude of the aircraft. Pitch, bank and heading attitude are represented by one moving element. This is a surface that symbolizes the natural horizon. This moves in three axes to indicate the change in all three parameters simultaneously. A fixed horizontal line on the indicator represents the aircraft.

You are the operator of a combined rotor-/fixed-wing based Unmanned Aerial Vehicle (UAV) of type Eagle Eye.

The Eagle Eye has a wingspan of 15.2 ft, is 17.9 ft in length, is 5.7 ft high, and weighs around 2,000 pounds (depending on payload).

The secure altitude is defined by 2500 feet. Below this altitude the risk of crashes and of being shot down by enemy fire soars.

Experiment Goals

The goal of this experiment is to test the two different flight instrument (traditional – Weber box) setups regarding their capabilities to support the operator of ground control station in controlling the aircraft. Of particular interest is to determine operator of increased workload and perception of unusual attitudes.

Experiment Schedule

You will conduct two sets of trials.

The order in which you will experience the two sets randomly assigned. The only difference between the sets is which set of flight instruments is used and the increased workload while operating two UAVs simultaneously.

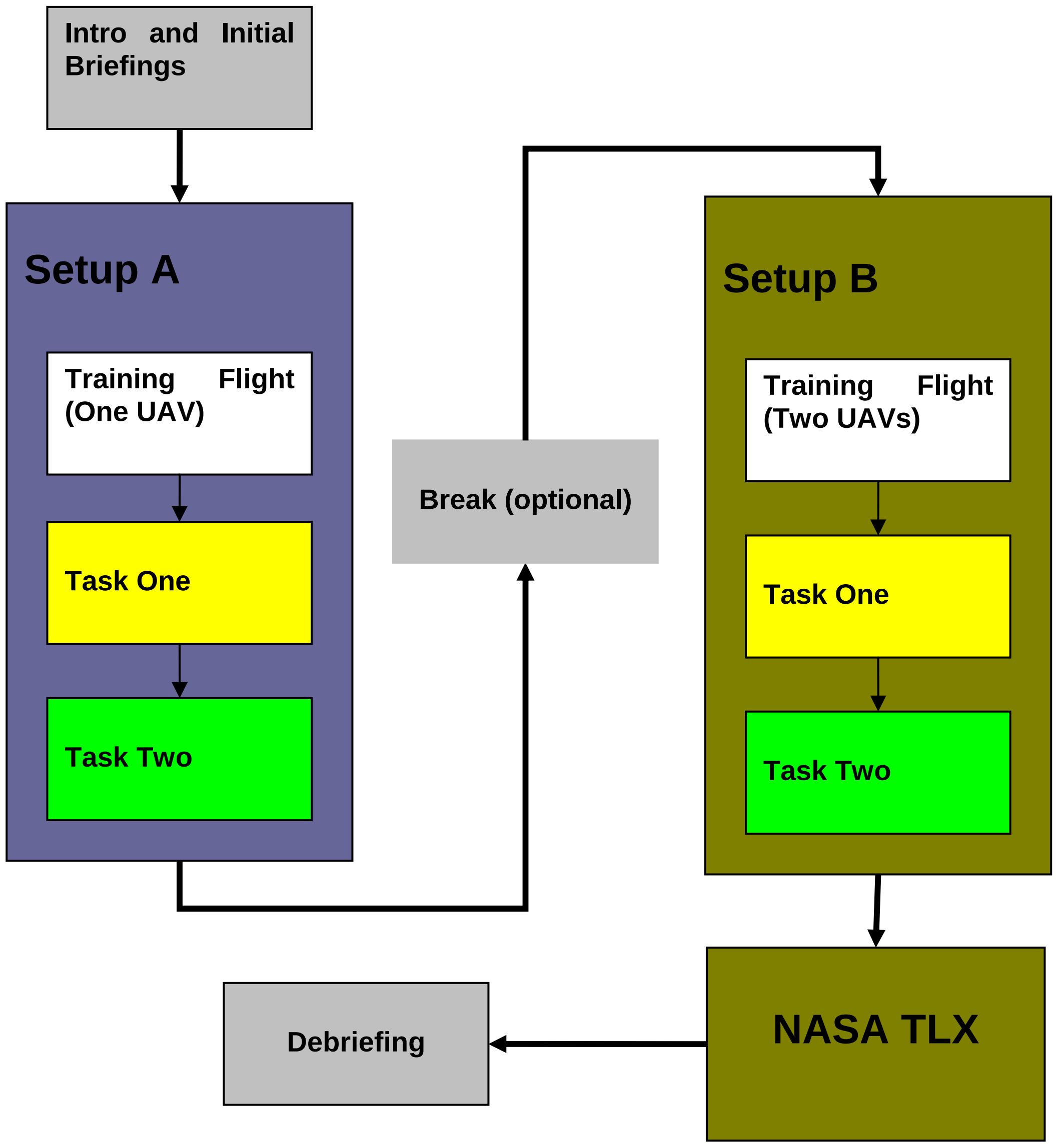
After the task briefing, you will get the opportunity to become familiar with operating the flight simulator software before you start with your assigned block of trials. After finishing your first block, you will have a short break to fill out a brief questionnaire, and then you will start with the second block of trials.

After you have finished both sets of trials you will be de-briefed and asked to respond to a post-experiment questionnaire.

Remember:

- You are a volunteer – we truly appreciate your time and willing to participate at our experiment!
- Please complete all trials if possible, but you can quit the experiment at any time if you need to.
- In case you might experience discomfort, please do not hesitate to inform the experimenter and please do not hesitate to abort the experiment if the level of discomfort is too high for you.
- All personal data will be handled confidentially and anonymously.

Experiment Schedule Diagram

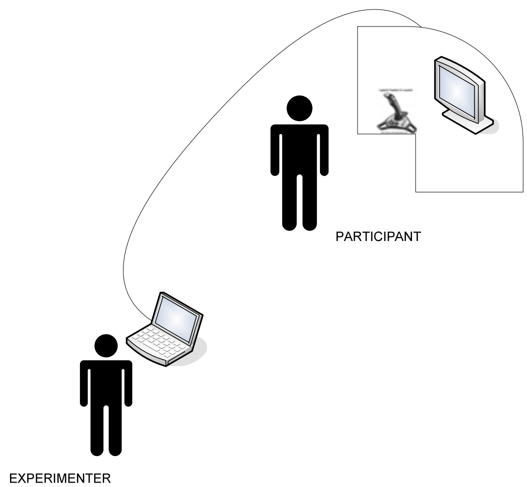


Task One

The UAV is on a test flight and enters a sector of high crosswinds. To simulate the broken data-link, you will be exposed to an unknown attitude of the aircraft.

Experiment Implementation

You will operate the UAV for 15 minutes or so. Periodically, the experimenter will give you the order to judge the current spatial attitude of the UAV. The simulation will freeze at this moment.



You will then hear the command “Stop Flying.” The monitor will be switched off and immediately after switched on again, simulating data link interruption. You will begin to evaluate your current spatial attitude using your flight instruments. When you feel you know what the current spatial attitude is like, say loudly “STOP.” At this moment the flight instruments will be switched off.

Now you have to express the observed spatial attitude of the UAV relative to the ground. You will do this by determining pitch and roll which you will draw on an orientation chart.

The time to accomplish this task and the accuracy of your spatial judgment will be measured.

You will have one test trial to become familiar with procedure.

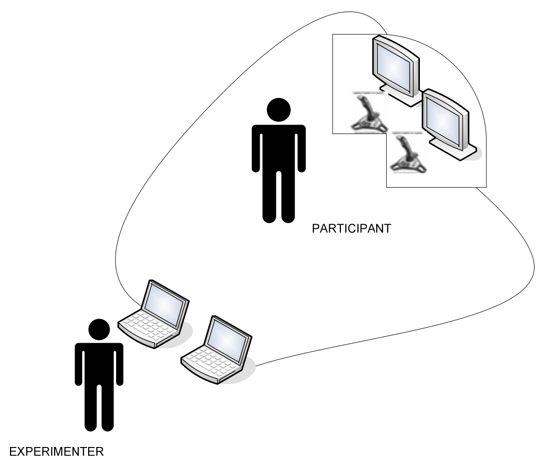
Do you have any questions?

Task Two

The UAVs are on a test flight and enter a sector of bad weather. The data-link connection to the UAVs was interrupted because of the weather conditions (simulated by switching off the monitor). When the data-link connection is reestablished, your task is to judge the current spatial attitude of the UAVs. The simulation will freeze at this moment.

Experiment Implementation

You will “fly” the UAVs for 15 minutes or so. Periodically, the experimenter will give you the order to judge the current spatial attitude of the UAVs. The simulation will freeze at this moment.



You will then hear the command “Stop Flying.” The Monitor will be switched off after immediately switched on again, simulating data link interruption. You will begin to evaluate your current spatial attitude using your flight instruments. When you feel you know what the current spatial attitude is like, say loudly “STOP.” At this moment the flight instruments will be switched off.

Now you have to express the observed spatial attitude of the UAVs relative to the ground. You will do this by determining pitch and roll which you will draw on an orientation chart.

The time to accomplish this task and the accuracy of your spatial judgment will be measured.

You will have one test trial to become familiar with procedure.

Do you have any questions?

APPENDIX E. QUESTIONNAIRES

Initial Questionnaire

Date:

The information is required for research and your name will not be used therefore please answer as fully and truthfully as possible.

Participant ID			
First Name:			
Middle Initial:			
Last Name:			
Age:			
Gender:	Male □ Female □		
Nationality:			
Are you experienced in aviation in any regard (incl. playing Flight Simulation Games)?	YES □	NO □	
Are you an aviator/pilot?	YES □	NO □	
Are you familiar with the basic set of flight instruments?	YES □	NO □	
Are you familiar with the basic flight controls to steer an airplane/control UAV?	YES □	NO □	
Did you operate any of these aircraft?: Fixed-Wing (Jet/Propeller), Rotor-Wing Aircraft, UAV	Fixed □ Rotor □ Propeller □	Jet □ UAV □	
How many flight hours do you have?		Hours	
How many hours in a flight simulator do you have?		Hours	
How long ago was your last flight?	Years	Month(s)	
How long ago was your last use of a flight simulator?	Years	Month(s)	
Are you trained in procedures of recovery from unusual attitude?	YES □ □	NO	

Post-Experiment Questionnaire

The information is required for research and your name will not be used therefore please answer as fully and truthfully as possible.

Participant ID	

Question	Answer-Options				
In general, how do you judge the difficulty of evaluating the current attitude of the UAV?	*Very easy*	*Somewhat easy*	*Border line*	*Somewhat complicated*	*Very difficult*
In general, how do you judge difficulty of using the traditional flight instruments for this task?	*Very easy*	*Somewhat easy*	*Border line*	*Somewhat complicated*	*Very difficult*
In general, how do you judge the difficulty of using the WEBER-Box for this task?	*Very easy*	*Somewhat easy*	*Border line*	*Somewhat complicated*	*Very difficult*
Did you feel better aware of the spatial orientation of the UAV with the WEBER-Box in comparison with the traditional flight instruments?	*Much less*	*Somewhat less*	*Border line*	*Somewhat more*	*Much more*
Did having the WEBER-Box increase or decrease your monitoring demands in comparison with the traditional flight instruments?	*Greatly decreased*	*Somewhat decreased*	*Unaffected*	*Somewhat increased*	*Greatly increased*
Did having the WEBER-Box increase or decrease your overall workload in comparison with the traditional flight instruments?	*Greatly decreased*	*Somewhat decreased*	*Unaffected*	*Somewhat increased*	*Greatly increased*
Did having the WEBER-Box increase or decrease your overall frustration level (irritate, stress, insecure) in comparison with the traditional flight instruments?	*Greatly decreased*	*Somewhat decreased*	*Unaffected*	*Somewhat increased*	*Greatly increased*
How would you characterize your Computer Skills	*None*	*Fair*	*Average*	*Good*	*Excellent*
How much experience do you have with computer games?	*None*	*Fair*	*Average*	*Good*	*Excellent*

Participant ID	

Comments/Suggestions/Opinions

In General:

Experiment Tasks:

WEBER-Box:

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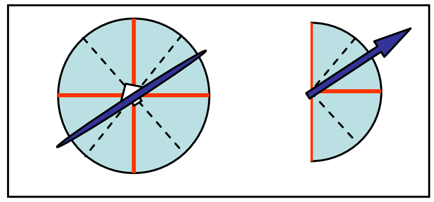
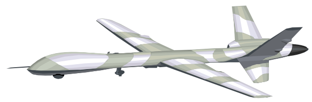
APPENDIX F. EVALUATION FORMS

Participant ID: …………

WEBER BOX: **YES** ☐ **NO** ☐

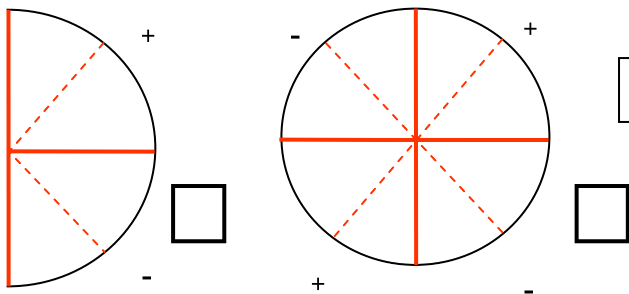




Test …

Pitch **Roll**

4



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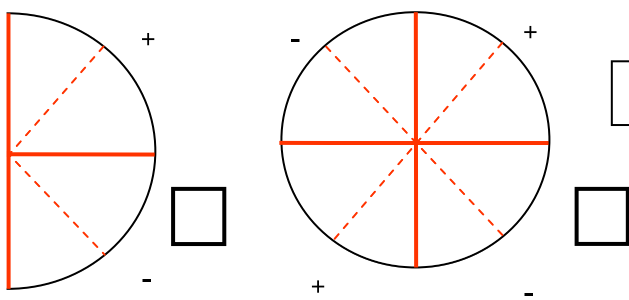

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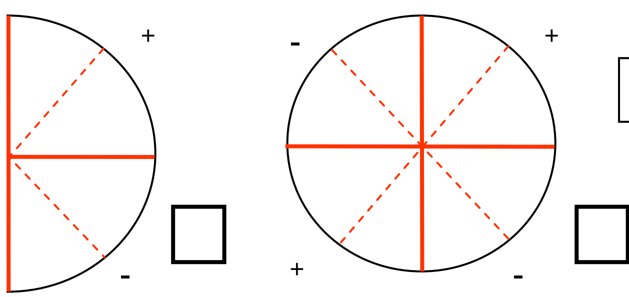

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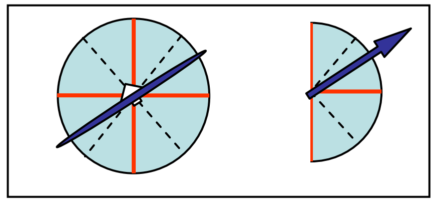
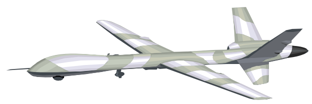
Participant ID: …………

WEBER BOX: YES ☐ **NO** ☐

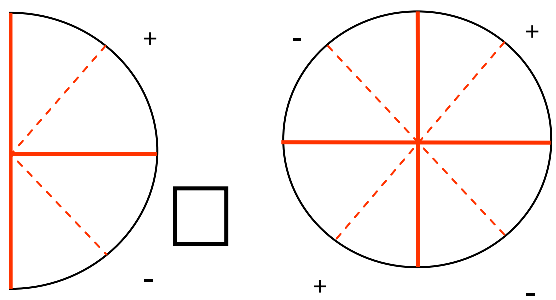




Test …

Pitch **Roll**

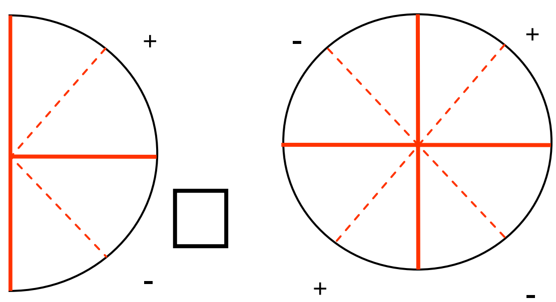
1



☐ ☐

sec.

5

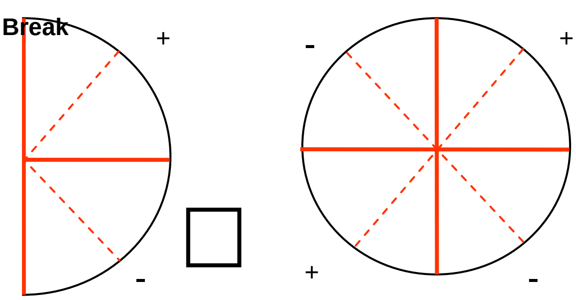


☐ ☐

sec.

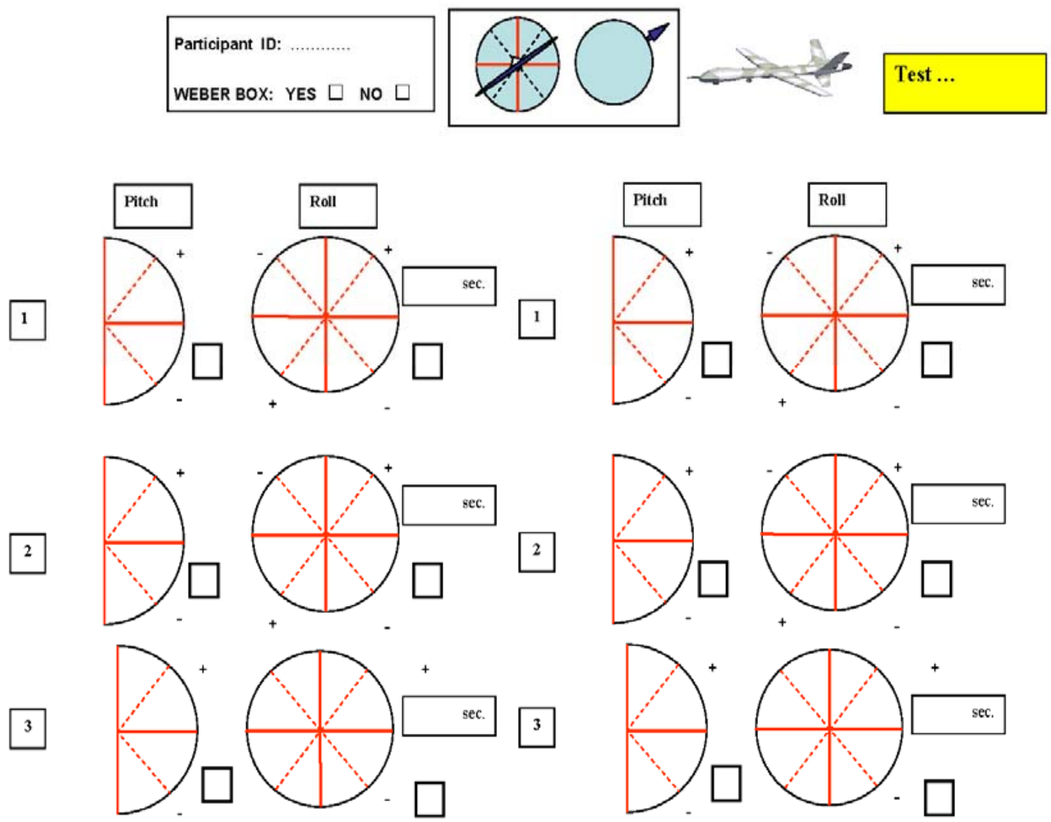
6

Break



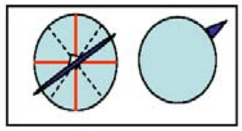
☐ ☐

sec.

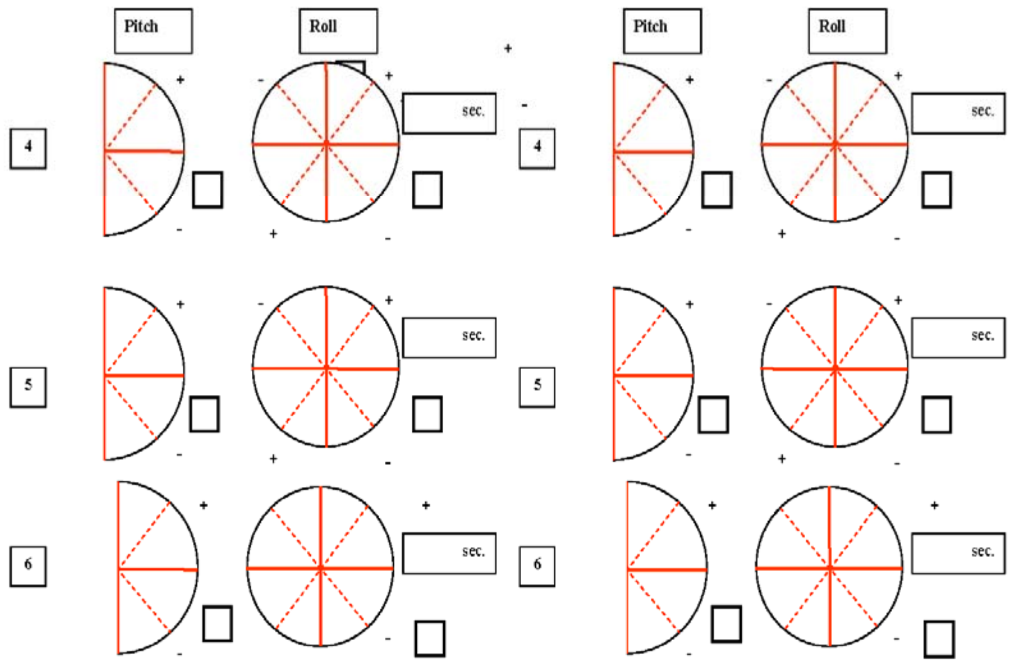

Participant ID: ....
WEBER BOX: YES ☐ NO ☐
Test ...
Pitch
Roll
Pitch
Roll
1
sec.
1
sec.
2
sec.
2
sec.
3
sec.
3
sec.

Participant ID: ....

WEBER BOX: YES ☐ NO ☐



Test ...



Pitch and Roll Setups

Test A

Trial	Pitch	Roll
D	-65	-150
C	-50	50
E	-45	100
F	45	-65
A	-75	120
B	-85	-30

Test B

Trial	Pitch	Roll
FandA	45and-75	-65and120
EandC	-45and-50	100and50
DandB	-65and-85	-150and-30
AandC	-75and-50	120and50
BandF	-85and45	-30and-65
CandD	-50and-65	50and-150

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APPENDIX G. NATIONAL AERONAUTICS AND SPACE ADMINISTRATION – TASK LOAD INDEX (NASA-TLX)

7. SUBJECT INSTRUCTIONS: SOURCES-OF-WORKLOAD EVALUATION

Throughout this experiment the rating scales are used to assess your experiences in the different task conditions. Scales of this sort are extremely useful, but their utility suffers from the tendency people have to interpret them in individual ways. For example, some people feel that mental or temporal demands are the essential aspects of workload regardless of the effort they expended on a given task or the level of performance they achieved. Others feel that if they performed well the workload must have been low and if they performed badly it must have been high. Yet others feel that effort or feelings of frustration are the most important factors in workload; and so on. The results of previous studies have already found every conceivable pattern of values. In addition, the factors that create levels of workload differ depending on the task. For example, some tasks might be difficult because they must be completed very quickly. Others may seem easy or hard because of the intensity of mental or physical effort required. Yet others feel difficult because they cannot be performed well, no matter how much effort is expended.

The evaluation you are about to perform is a technique that has been developed by NASA to assess the relative importance of six factors in determining how much workload you experienced. The procedure is simple: You will be presented with a series of pairs of rating scale titles (for example, Effort vs. Mental Demands) and asked to choose which of the items was more important to your experience of workload in the task(s) that you just performed. Each pair of scale titles will appear on a separate card.

Circle the Scale Title that represents the more important contributor to workload for the specific task(s) you performed in this experiment.

After you have finished the entire series we will be able to use the pattern of your choices to create a weighted combination of the ratings from that task into a summary workload score. Please consider your choices carefully and make them consistent with how you used the rating scales during the particular task you were asked to evaluate. Don't think that there is any *correct* pattern: we are only interested in your opinions.

If you have any questions, please ask them now. Otherwise, start whenever you are ready. Thank you for your participation.

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Appendix A.

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*Perfect/Failure*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

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Appendix B.

Sources-of-Workload Comparison Cards

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand

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Appendix D.

Subject ID: ____________ Date: ____________

SOURCES-OF-WORKLOAD TALLY SHEET		
Scale Title	*Tally*	*Weight*
MENTAL DEMAND		
PHYSICAL DEMAND		
TEMPORAL DEMAND		
PERFORMANCE		
EFFORT		
FRUSTRATION		

Total count = ____________

(NOTE - The total count is included as a check. If the total count is not equal to 15, then something has been miscounted. Also, no weight can have a value greater than 5.)

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Appendix E.

Subject ID: ____________ Task ID: ____________

WEIGHTED RATING WORKSHEET			
Scale Title	*Weight*	*Raw Rating*	*Adjusted Rating* (Weight X Raw)
MENTAL DEMAND			
PHYSICAL DEMAND			
TEMPORAL DEMAND			
PERFORMANCE			
EFFORT			
FRUSTRATION			

Sum of "Adjusted Rating" Column = ________

WEIGHTED RATING =
[i.e., (Sum of Adjusted Ratings)/15]

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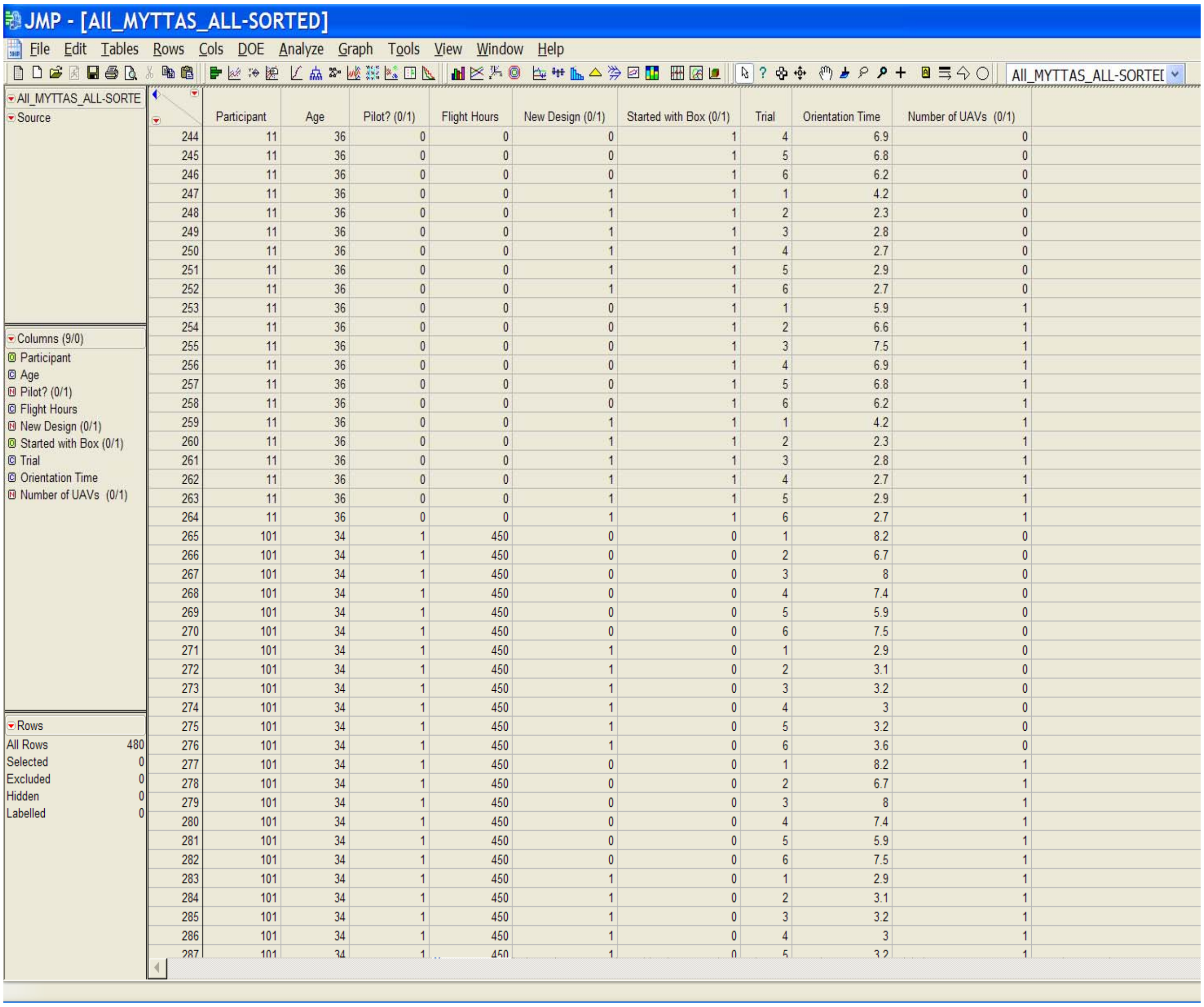
APPENDIX H. EXPERIMENT DATA



	Participant	Age	Pilot? (0/1)	Flight Hours	New Design (0/1)	Started with Box (0/1)	Trial	Orientation Time	Number of UAVs (0/1)
244	11	36	0	0	0	1	4	6.9	0
245	11	36	0	0	0	1	5	6.8	0
246	11	36	0	0	0	1	6	6.2	0
247	11	36	0	0	1	1	1	4.2	0
248	11	36	0	0	1	1	2	2.3	0
249	11	36	0	0	1	1	3	2.8	0
250	11	36	0	0	1	1	4	2.7	0
251	11	36	0	0	1	1	5	2.9	0
252	11	36	0	0	1	1	6	2.7	0
253	11	36	0	0	0	1	1	5.9	1
254	11	36	0	0	0	1	2	6.6	1
255	11	36	0	0	0	1	3	7.5	1
256	11	36	0	0	0	1	4	6.9	1
257	11	36	0	0	0	1	5	6.8	1
258	11	36	0	0	0	1	6	6.2	1
259	11	36	0	0	1	1	1	4.2	1
260	11	36	0	0	1	1	2	2.3	1
261	11	36	0	0	1	1	3	2.8	1
262	11	36	0	0	1	1	4	2.7	1
263	11	36	0	0	1	1	5	2.9	1
264	11	36	0	0	1	1	6	2.7	1
265	101	34	1	450	0	0	1	8.2	0
266	101	34	1	450	0	0	2	6.7	0
267	101	34	1	450	0	0	3	8	0
268	101	34	1	450	0	0	4	7.4	0
269	101	34	1	450	0	0	5	5.9	0
270	101	34	1	450	0	0	6	7.5	0
271	101	34	1	450	1	0	1	2.9	0
272	101	34	1	450	1	0	2	3.1	0
273	101	34	1	450	1	0	3	3.2	0
274	101	34	1	450	1	0	4	3	0
275	101	34	1	450	1	0	5	3.2	0
276	101	34	1	450	1	0	6	3.6	0
277	101	34	1	450	0	0	1	8.2	1
278	101	34	1	450	0	0	2	6.7	1
279	101	34	1	450	0	0	3	8	1
280	101	34	1	450	0	0	4	7.4	1
281	101	34	1	450	0	0	5	5.9	1
282	101	34	1	450	0	0	6	7.5	1
283	101	34	1	450	1	0	1	2.9	1
284	101	34	1	450	1	0	2	3.1	1
285	101	34	1	450	1	0	3	3.2	1
286	101	34	1	450	1	0	4	3	1
287	101	34	1	450	1	0	5	3.2	1

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